Effect of sequencing rules on order release policies in a stochastic and dynamic job shop with sequence-dependent setup times – a simulation study

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Abstract. Order review and release in job shop with sequence-dependent setup times is one of the most complex job shop scheduling problems. This article analyses the effect of sequencing rules on different order release policies for performance measures i.e. mean throughput time, total setups, mean setup time, number of tardy jobs and makespan in a stochastic and dynamic job shop with sequence-dependent setup time. Four sequencing rules, viz. first-come-first-serve, planned release date, earliest due date, shortest processing time and five order review and release policies i.e. aggregate workload trigger, workcentre workload trigger, corrected workload trigger, upper bound release and lancaster university management school corrected order release are taken into consideration. A simulation model using Promodel® is developed for experimental purpose. Results indicate that for a given order review and release policy, there is an effect of sequencing rule in a stochastic and dynamic environment with consideration of sequence-dependent setup time and the best performing sequencing rule is different for different order review and release policies for a given performance measure.

Keywords: Sequencing rules, order review and release, sequence-dependent setup times, simulation

1. Introduction
Order review and release (ORR) works as a boundary between the shop floor and planning system [Bergamaschi et al. (1997)]. In ORR, when a job comes in the preshop pool, it is not released immediately. Before releasing to shop floor, the jobs are kept in preshop pool which acts as a buffer for incoming jobs and sequencing rules are applied for sequencing of jobs in preshop pool. ORR determines the time for release of order on the shop floor so that orders can be completed on time. From literature, it was found that release of order on the shop floor is either based on periodic or continuous basis [Thurer et al. (2012a), Thurer et al. (2014b)]. In periodic release, orders are released on the shop floor at periodic time interval (once a day, shift, week etc.) and in continuous release; the orders are released at any time. The main objective of ORR policy is to balance the queue length and work-in-process on the shop floor. For selecting jobs from preshop pool, sequencing rules viz. first-come-first-serve (FCFS), planned release date (PRD), shortest processing time (SPT) and earliest due date (EDD) are used. Further, as the job reaches the shop floor and waits in front of the machine, dispatching rule viz. EDD, FCFS and SPT are utilised to select a job waiting for processing on the
machine. Setup time is required for preparation of resources to perform a task [Allahverdi et al. (2008)]. Setup time is divided into two types i.e. sequence-dependent and sequence-independent. If setup time depends on both preceding task and the task, it is known as sequence-dependent and if setup time depends only on the task to be processed, it is called sequence-independent [Allahverdi et al. (2008)]. In an industrial survey, it is found that 70% of schedulers have deal with sequence-dependent setup time (SDST) [Luh et al. (1998)]. This study is a contribution to the available literature on job shop with SDST. This paper investigates the effect of sequencing rules in job shop with SDST in a stochastic and dynamic environment using discrete event simulation approach.

2. Literature review and problem formulation

There is a limited literature available on ORR in a job shop with SDST. Kim and Bobrowski (1995) investigated the influence of SDST in job shop with ORR. They considered four dispatching rules viz. job of smallest critical ratio, critical ratio, similar setup, smallest processing time and four ORR policies viz. forward finite loading, maximum shop load, immediate release and backward infinite loading. Authors concluded that ORR policy is very effective when used in combination with ordinary dispatching rules (smallest processing time, critical ratio). Missbauer and Hubert (1997) investigated the influence of SDST on the relationship between the setup time, dispatching rule and work-in-process. They considered single machine with order release algorithm and two dispatching rules viz. first-come-first-serve and maximum savings setup time. They found that there is a significant effect of work-in-process level on the system performance when SDST exist. Thurer et al. (2012a) evaluated the performance of ORR policies in job shop with SDST. Jobs are selected for release on the shop floor periodically as per shortest slack. They considered six dispatching rules i.e. first-come-first-serve, jobs with smallest critical ratio, similar setup, planned operation start time, setup-oriented planned operation start time and setup oriented shortest processing time and included two performance measures in their study i.e. throughput time and percentage tardy. Authors concluded that there is improvement in the performance when ORR is used with set-up oriented dispatching rules. Thurer et al. (2014b) addressed the effect of SDST on workload controlled job shops. Authors considered four ORR policies i.e. periodic, SLAR, WCPRD and LUMSCOR and two dispatching rules viz. planned operation start time and setup oriented planned operation start time. They considered three performance measures i.e. throughput time, lead time and percentage of tardy jobs. Authors concluded that combination of periodic and continuous (LUMSCOR) ORR policy gives the best performance.

Several studies were carried out on ORR policies in a job shop environment. The important contributions are discussed below:

Thurer et al. (2013) addressed the problem concerning order release in multi-stage job shop and concluded that SLAR and LUMSCOR are best-performing ORR policies. Thurer et al. (2014a) worked on continuous workload control ORR and assessed the effect of sequencing rules on ORR policies in a job shop and concluded that sequence of jobs by which the jobs are released has a significant effect on performance i.e. mean lead time, mean throughput time, mean tardiness and percentage tardy.

Literature review indicate that no attempt has been made in past to evaluate the effect of sequencing rules in a job shop with SDST in a stochastic and dynamic environment. In the present paper, an attempt is made in this direction and the problem is defined as follows: “There is a job shop consisting of ‘m’ machines.” The shop can process ‘n’ jobs simultaneously and each job requires several operations to be completed. The operation incurs a sequence-dependent setup time and shop operates in a stochastic and dynamic environment. When a job comes at the shop, it is not released immediately. There is an ORR policy in action. The objective is to assess the effect of sequencing rules i.e. EDD, FCFS, SPT and PRD on the various ORR policies i.e. AGGWLT, WCWLT, CorrWLT, LUMSCOR and UBR for performance measures i.e. mean throughput time, total setups, mean setup time, number of tardy jobs and makespan. The following assumptions in line with previous study [Thurer et al. (2014b)] are made in the present work i.e. (i) At a time only one operation can be performed on each machine (ii) An operation begins after the last operation has been
completed (iii) Dynamic arrival of jobs is considered (iv) Infinite capacity buffer is used before each machine (v) Setup times and processing times are considered stochastic in nature.

3. Simulation model

3.1. Job and shop configuration

In the present work, a job shop consisting of six machines is taken into consideration [Thurer et al. (2012a), Thurer et al. (2014b)]. Six different job types arrive in the manufacturing system with equal probability and different routing. The routing of different job types is shown in Table 1. For different job types, processing times changes according to routing on machines and processing times of jobs on machines as per routing are shown in Table 2. All machines have equal probability of being visited and the number of operations varies from four to six. The processing time and setup time of each job is stochastic in nature and uniformly distributed and same job types have similar setup time requirement. As job type is changed, setup requirement also changes, as shown in Table 3.

| Table 1: Routing of different job types on machines |
|---|---|---|
| Job type | Operations | Routing on Machines |
| 1 | 6 | 1-5-4-2-3-6 |
| 2 | 5 | 2-4-6-3-5 |
| 3 | 5 | 3-1-2-5-4 |
| 4 | 4 | 4-5-1-6 |
| 5 | 4 | 5-1-2-3 |
| 6 | 6 | 6-2-1-5-4-3 |

| Table 2: Processing times of different job types as per routing on machines |
|---|---|
| Job type | Processing times |
| 1 | U(9,10), U(10,11), U(13,14), U(11,12), U(8,9), U(12,13) |
| 2 | U(10,11), U(9,10), U(14,15), U(11,12), U(13,14) |
| 3 | U(16,17), U(9,10), U(12,13), U(10,11), U(11,12) |
| 4 | U(11,12, U(10,11), U(12,13), U(13,14) | |
| 5 | U(12,13), U(11,12), U(10,11), U(9,10) |
| 6 | U(18,19), U(9,10), U(10,11), U(10,11), U(6,7), U(11,12) |

3.2. Inter-arrival time

In the present work, Mean inter-arrival time is computed by the following manner [Yu and Ram (2006), Vinod and Sridharan (2008)].

\[
c = \frac{1}{\mu} = \frac{U_p U_g}{SN} \tag{1}
\]

c = Mean inter-arrival time; \(\mu\) = Mean job arrival rate; \(U_p\) = Sum of mean processing time of all operations and mean setup times; \(U_g\) = Mean number of operations per job; \(S\) = Shop utilization and \(N\) = Number of machines. In the present work, \(U_p = 20.87\) and \(U_g = 5\). The experiments are conducted at shop utilization level of 95%.

3.3. Due date
Due date is calculated by the following formula \[\text{Holthaus et al. (1997), Yu and Ram (2006), Vinod and Sridharan (2008)}\].

\[ dt_i = at_i + k(pt_i + no_i \times v_i) \]  

Here, \(dt_i\) = Due date of job \(i\); \(at_i\) = Arrival time of job \(i\); \(pt_i\) = Mean total processing times of all the operations of job \(i\); \(no_i\) = Number of operations of job, \(v_i\) = Mean of mean setup times of all the changeover of job \(i\) and \(k\) = Due date tightness factor. In this study, due date tightness factor is taken as 3.

| Preceding Job Type | A   | B   | C   | D   | E   | F   |
|--------------------|-----|-----|-----|-----|-----|-----|
| 1                  |     | 0   | U (11,11.25) | U (11,11.75) | U (11,11.50) | U (11,11.50) | U (11,11.25) |
| 2                  | U (11,11.50) |     | 0   | U (11,11.25) | U (11,11.75) | U (11,11.50) | U (11,11.50) | U (11,11.50) |
| 3                  | U (11,11.25) | U (11,11.50) |     | 0   | U (11,11.50) | U (11,11.75) | U (11,11.25) |
| 4                  | U (11,11.75) | U (11,11.25) | U (11,11.50) |     | 0   | U (11,11.25) | U (11,11.50) |
| 5                  | U (11,11.50) | U (11,11.75) | U (11,11.25) | U (11,11.50) |     | 0   | U (11,11.25) |
| 6                  | U (11,11.25) | U (11,11.50) | U (11,11.50) | U (11,11.75) | U (11,11.25) |     | U (11,11.50) |

3.4. Order release policies
In the present work, five ORR policies viz. aggregate workload trigger, workcentre workload trigger, corrected workload trigger, upper bound release and lancaster university management school corrected order release are considered [Thurer et al. (2012a), Thurer et al. (2013), Thurer et al. (2014a), Thurer et al. (2014b)].

3.5. Sequencing rules
In the present work, the sequencing rules viz. first-come-first-serve, earliest due date, shortest processing time and planned release date are considered to select a job from the preshop pool [Hendry and Wong (1994), Sabuncuoglu and Karapinar (1999), Enns et al. (2002), Thurer et al. (2014a)].

3.6. Dispatching rule
In the present work, shortest processing time dispatching rule is taken into consideration. As per this rule a job is selected for dispatching according to shortest processing time.

3.7. Validation of simulation model
For validation purpose, a verification exercise is conducted on the simulation model. The output obtained is compared with the manual exercise with same input data and the simulation model is run for different settings in order to check whether the simulation model behaves logically or not.

4. Experimental design and performance measure
A full factorial design approach is used in the present work to assess the effect of sequencing rules on system performance. Here, each experiment consists of 30 replications and each replication runs for 20000 jobs completion after warmup period. In the present work, welch procedure by Law and Kelton [1] is used to determine the warmup period and it indicate that system comes to steady state after completion of 5000 jobs.

5. Results and discussion
Results are presented and discussed as per the system performance measures and described below

5.1. Mean throughput time
Table 4 shows the results for mean throughput time for five ORR policies. It indicates that for AGGWLT ORR policy, the system performance measure i.e. mean throughput time varies as the sequencing rule is changed from FCFS to SPT. This observation is true for other ORR policies also. Thus, as sequencing rules changes for a given ORR policy, there is a change in the mean throughput time. For AGGWLT ORR policy, the least mean throughput time is obtained for SPT sequencing rule. Similarly, for WCWLT ORR policy, minimum mean throughput time is obtained for PRD sequencing rule.

**Table 4: Mean throughput time**

| Sequecing rule | AGGWLT  | WCWLT  | CorrWLT | LUMSCOR | UBR   |
|----------------|---------|--------|---------|---------|-------|
| FCFS           | 662.64  | 663.65 | 664.56  | 660.56  | 655.95|
| PRD            | 659.21  | 656.44 | 665.37  | 664.92  | 658.52|
| EDD            | 662.64  | 663.65 | 664.56  | 660.56  | 655.95|
| SPT            | 655.94  | 658.03 | 658.45  | 659.67  | 659.33|

Legend: Bold and italics indicate the minimum performance measure for the ORR policy

For CorrWLT ORR policy, SPT sequencing rule yield minimum performance measure and for LUMSCOR as well as UBR ORR policies, FCFS and EDD yield the best performance. Thus, there is an effect of sequencing rule on a given ORR policy and best performing sequencing rule is different for different ORR policy for mean throughput time performance measure.

### 5.2. Total setups

Table 5 provides the results for total setups for five ORR policies. It is evident that for AGGWLT ORR policy, the system performance measure i.e. total setups varies as the sequencing rule is changed from FCFS to SPT. This observation is true for other ORR policies also. For AGGWLT ORR policy, the least total setups are obtained for PRD sequencing rule. Similarly, for WCWLT ORR policy, minimum total setups are obtained for SPT sequencing rule. For CorrWLT ORR policy, PRD sequencing rule gives best performance. SPT sequencing rule provides best results for both LUMSCOR and UBR ORR policies. Thus, as sequencing rules changes for a given ORR policy, there is a change in total setups. Thus, there is an effect of sequencing rule on a given ORR policy and best performing sequencing rule is different for different ORR policy.

**Table 5: Total setups**

| Sequecing rule | AGGWLT  | WCWLT  | CorrWLT | LUMSCOR | UBR   |
|----------------|---------|--------|---------|---------|-------|
| FCFS           | 109040  | 120282 | 108944  | 108944  | 107000|
| PRD            | 107980  | 119305 | 106854  | 108904  | 107163|
| EDD            | 109037  | 120278 | 108942  | 108937  | 107000|
| SPT            | 108054  | 107034 | 106973  | 108673  | 106826|

Legend: Bold and italics indicate the minimum performance measure for the ORR policy

### 5.3. Mean setup time

Table 6 provides the results for mean setup time for five ORR policies. It shows that for AGGWLT ORR policy, the system performance measure i.e. mean setup time varies as the sequencing rule is changed from FCFS to SPT. This observation is also true for other ORR policies also. For AGGWLT ORR policy, the minimum setup time is obtained for PRD sequencing rule. Similarly, for WCWLT ORR policy, minimum setup time is obtained for SPT sequencing rule. For CorrWLT ORR policy, FCFS as well as EDD sequencing rule gives the best performance. SPT sequencing rule provides best results for both LUMSCOR and UBR ORR policies. Thus, as sequencing rules changes for a given ORR policy, there is a change in mean setup time performance measure.
Table 6: Mean setup time

| Sequencing rule | Release rules |
|-----------------|--------------|
|                 | AGGWLT | WCWLT | CorrWLT | LUMSCOR | UBR     |
| FCFS            | 48.02  | 52.9  | 46.91   | 47.96   | 47.08   |
| PRD             | 47.53  | 52.52 | 47.05   | 47.93   | 47.19   |
| EDD             | 48.01  | 52.9  | 46.91   | 47.96   | 47.07   |
| SPT             | 47.59  | 47.09 | 47.08   | 47.85   | 47.06   |

Legend: Bold and italics indicate the minimum performance measure for the ORR policy. Therefore, there is an effect of sequencing rule on a given ORR policy and best performing sequencing rule is different for different ORR policy for mean setup time.

5.4. Makespan

Table 7 shows the results for makespan for five ORR policies. It is evident that for AGGWLT ORR policy, the makespan varies as the sequencing rule is changed from FCFS to SPT. This observation is true for other ORR policies also. For AGGWLT ORR policy, the least makespan is obtained for PRD sequencing rule. Similarly, for WCWLT ORR policy, minimum makespan is obtained for SPT sequencing rule. For CorrWLT ORR policy, PRD sequencing rule yield minimum performance measure and for LUMSCOR as well as UBR ORR policies, SPT sequencing rule provides the best performance.

Table 7: Makespan

| Sequencing rule | Release rules |
|-----------------|--------------|
|                 | AGGWLT | WCWLT | CorrWLT | LUMSCOR | UBR     |
| FCFS            | 510260.6 | 558400.1 | 511449.1 | 503446.5 | 507875.2 |
| PRD             | 498620.4 | 552702.7 | 508755.8 | 502412.3 | 508671.3 |
| EDD             | 510260.6 | 558400.1 | 511449.1 | 503446.5 | 507875.2 |
| SPT             | 501731.6 | 506225.3 | 511860.6 | 498880.7 | 507082.1 |

Legend: Bold and italics indicate the minimum performance measure for the ORR policy. Thus, as sequencing rules changes for a given ORR policy, there is a change in the makespan. Thus, there is an effect of sequencing rule on a given ORR policy and best performing sequencing rule is different for different ORR policy for makespan performance measure.

5.5. Number of tardy jobs

Table 8 shows the results for number of tardy jobs for five ORR policies. It indicates for AGGWLT ORR policy, the system performance measure i.e. number of tardy jobs varies as the sequencing rule is changed from FCFS to SPT. This observation is true for other ORR policies also. For AGGWLT ORR policy, the least numbers of tardy jobs are obtained for SPT sequencing rule. Similarly, for WCWLT ORR policy, the minimum numbers of tardy jobs are obtained for PRD sequencing rule. For CorrWLT ORR policy, SPT sequencing rule yield the best performance and for LUMSCOR as well as UBR ORR policies, EDD sequencing rule gives the best performance.

Table 8: Number of tardy jobs

| Sequencing rule | Release rules |
|-----------------|--------------|
|                 | AGGWLT | WCWLT | CorrWLT | LUMSCOR | UBR     |
| FCFS            | 5112   | 4891  | 5243   | 4982    | 5114    |
| PRD             | 5057   | 4884  | 5303   | 5086    | 5165    |
| EDD             | 5078   | 4891  | 5220   | 4923    | 5102    |
| SPT             | 5023   | 5179  | 5121   | 5069    | 5156    |

Legend: Bold and italics indicate the minimum performance measure for the ORR policy.
Thus, as sequencing rules changes for a given ORR policy, there is a change in the number of tardy jobs. Thus, there is an effect of sequencing rule on a given ORR policy and best performing sequencing rule is different for different ORR policy.

6. Conclusions
In the present paper, an attempt is made to assess the effect of sequencing rules i.e. FCFS, SPT, EDD, PRD on ORR policies viz. AGGWLT, WCWLT, CorrWLT, LUMSCOR, UBR in a job shop with SDST operating in a stochastic and dynamic environment. Mean throughput time, mean setup time, total setups, makespan and number of tardy jobs are taken as system performance measures. Results indicate that in a stochastic and dynamic job shop with SDST, there is an effect of sequencing rules on the ORR policy for a given performance measure. Further the best performing sequencing rule is different for different ORR policy for the given performance measure.

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