*IJMS*, *Vol. 15, Nos. 1-2, (January-June 2016), pp. 187-196*

ISSN: 0972-754X

# HEURISTICS TECHNIQUES FOR MULTI-MACHINE FLOW SHOP SCHEDULING PROBLEMS WITH SEQUENCE DEPENDENT SETUP TIME

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## Abstract

Bi-criteria flow shop scheduling problem with sequence dependent setup time has been studied in this paper. The objective is to minimize the weighted sum of makespan and system utilization time. In referred objective equal weights are given to both the criterion. To solve this problem the mathematical model has been developed. Since the flow shop scheduling problem with sequence dependent setup time is NP-hard therefore three heuristics has been developed. Computation analysis is carried out over system of varying sizes of job and machine environments with processing time is following the uniform distribution in [1,99]. The setup is generated uniformly as 25%, 50% and 100% of processing time. The computation results depict that proposed model is effective in solving the referred problem.


***Keywords*:** Scheduling, Flow shop, Makespan, System Utilization Time, Heuristic.

## 1. INTRODUCTION

Flow shop scheduling deals with the scheduling of *n* jobs over available system of *m* machines, where each machine is to perform some specific operation. The technological constraint of flow shop scheduling environment demands that the flow of all the jobs over system of machines is unidirectional which implies if first job is processed first on machine $M_i$ then on $M_{i+1}$, $\forall\, i = 1, 2, .., m - 1$, then same is route for all the remaining jobs of the schedule. Moreover, fixed job schedule is processed over the system of machines with no preemption constraint. Setup time may be defined as the time required to prepare the machine to process the particular job. Machine setup time includes the positioning the job to be processed on particular machine, cleaning the tools, fixing the required equipments, adjusting all the tools etc. The scheduling problems involving setup time as independent processing factor can be classified as: sequence dependent setup time and sequence independent setup time. Sequence dependent setup time is more complicated in scheduling environment as compare to sequence independent setup time. The setup time that depends on both the job to be processed and job preceding it, is called as sequence dependent setup time whereas that depends only on the job to be processed is called sequence independent setup time.

The industrial environment where the sequence dependent setup time is followed involves:

(i) The chemical manufacturing industries, where the amount of time required for cleansing of machine depends upon the chemical component next to manufacture and current one.

(ii) The printing industries, where the cleansing and setting of dyes depends on the type of paper and the colour of dye used in previous printing.

The constraint of sequence dependent setup time is found in many industrial environments including dye changing and cutter size adjustment in paper industries, stamping in plastic manufacturing industries, roller size in container manufacturing industries (Al-lahverdi (2015)). Flow shop scheduling problems with sequence dependent setup time has been widely studied in literature. The tremendous contribution to the literature of flow shop scheduling problem with sequence dependent setup time has been done by Cheng et.al. (2000) and Allahverdi (2015). Gagne et.al.(2002), Rabadi et.al.(2004), Ruiz et.al. (2005), Gupta and Smith (2006), Mirabi (2011) concentrated on single criteria flow shop schedul- ing problem.

Bicriteria flow shop scheduling problems concentrate on two criteria of scheduling simultaneously. Bicriteria scheduling problems can be classified into three classes. In first class one of the two criteria is to be considered as objective to be optimized (Secondary criteria) and the second considered as constraint (Primary Criteria). In second class weighted sum of both criteria is considered as objective to be optimized. In third class both criteria are considered as objective function and final schedule to be processed on available system of machines depends upon the decision of manufacturer. Lin and Wu (2007) studied the two-machine flow shop scheduling problem with setup time as part of processing time.

Mansouri et.al.(2009), Gupta et.al. (2013) considered two machine flow shop scheduling with different parameters involving sequence de- pendent setup time. Eran (2010) developed mathematical model for *m* machine bicriteria flow shop scheduling problem of mini- mizing weighted sum of makespan and total completion time with sequence dependent setup time with assumption that system idle time may be positive.

In this paper the mathematical model for *m* stage flow shop scheduling problem with sequence dependent setup time is developed where objective is to optimize weighted sum of makespan and system utilization time. System utilization time is total time span for which the system was actually in use during processing of all the jobs. It includes both the system idle time and sum of processing time of all the jobs over available system of machines. System utilization time is important when either high production cost machines are to be used during manufacturing or it is preferable to take the machine on lease than to be purchased. System utilization time has direct influence on rental cost and hence overall production/ manufacturing cost, therefore it is an important criterion to be studied in scheduling environment. Makespan is another important tool of scheduling minimization of which always increases system performance. The system utilization time will be minimized if idle time of all the machines is zero. However, for the models with no idle time the makespan is not given much importance. Such models of no-idle time on machines are considered by Narain and Bagga (2005). Our work is an extension of this work in general scheduling environment.

The rest of paper is organized as follows: Problem definition is given in section 2. In section 3 the complexity of model is studied and heuristics are developed to solve referred problem. Computation analysis to study effectiveness of developed model and heuristics to solve considered problem is carried out in section 4. In section 5 final conclusion is made with future extension.

## 2. PROBLEM DEFINITION

Let the sequence of $n$ jobs given by $\{1, 2, 3, .., n\}$ is to be sched- uled on system of $m$ machines. The processing time of each job $j$ over the machine $i$ is given by $p_{i,j}$ which is well known in ad- vance. $S_{i,jk}$ is setup time of machine $i$ when the job $k$ is processed after job $j$ on this machine. The objective is to minimize weighted sum of makespan and system utilization time.

### 2.1 Assumptions

Following are the main assumptions of proposed model :

1. All the jobs are available for processing over system of ma- chines at time zero.
2. Each machine can operate on single job at particular time.
3. Each machine can perform single particular operation.

4. No two operations can be performed on particular job simulta- neously.
5. The job $j$ can leave the machine $i$ only when its processing is completed on particular machine.
6. Each job has to visit each machine exactly once.
7. Setup time is independent factor of job processing.
8. Machine idle time can be positive quantity.

## 2.2 Notations

Following notations are used in progress of paper:

$n$ number of jobs

$m$ number of machines

$j$ index of $j^{th}$ job

$i$ index of $i^{th}$ machine

$p_{i,j}$ processing time of $j^{th}$ job on $i^{th}$ machine

$S_{i,jk}$ setup time on machine $i$ for processing job $k$ after the job $j$ being

$C_{max}$ maximum completion time

$C_{i,j}$ completion time of job $j$ on machine $i$ $UT$ Total system utilization time

$IT_{i,j}(\sigma)$ idle time of machine $i$ for job $j$ of sequence $ó$

$d_i(ó)$ delay time when the machine $i$ starts processing the first job of se

$Ci2\ , j(\sigma)$ completion time of job $j$ of sequence $ó$ on machine $i$ when it star

$UT^{2}(\sigma)$ system utilization time when the delay time is implemented

$w1$ weight for makespan

## 2.3 Mathematical Model

To solve the flow shop scheduling problem with dual criteria of makespan and system utilization time mixed integer programming (MIP) model has been developed. Following variables are used as decision variables:

$$UT = \sum_{j=1}^{n} IT_{m,j} + \sum_{j=1}^{m}\sum_{i=1}^{n} p_{i,j}$$

$Y_{j,k}$ = 1 if job $j$ is scheduled at position $k$ in final schedule, 0 otherwise $\forall\, j, k = 1, 2, 3..., n$

$C_{i,j} \geq 0 \;\forall\; i = 1, 2, .., m; j = 1, 2, .., n$

Mathematical model is given as:

**Objective Function**

$$min\ \ Z = (w1 \times C_{max}) + ((1 - w1) \times UT) \tag{1}$$

**Subject to**

$$C_{max} - C_{i,j} \geqslant 0\ \ \forall i = 1, 2, ..., m; j = 1, 2, 3...., n \tag{2}$$

$$C_{i,j} - C_{i-1,j} \geqslant \sum_{k=1}^{n} p_{i,j}.Y_{j,k}\ \ \forall i = 1, 2, ..., m; j = 1, 2, 3...., n \tag{3}$$

$$C_{i,j} - C_{i,j-1} \geqslant \sum_{k=1}^{n} (S_{i,(j-1)j} + p_{i,j}).Y_{j,k}\ \ \forall i = 2, ..., m; j = 1, 2, 3...., n \tag{4}$$

$$\sum_{k=1}^{n} Y_{j,k} = 1 \quad \forall j = 1, 2, 3, ..., n \tag{5}$$

$$\sum_{j=1}^{n} Y_{j,k} = 1 \quad \forall k = 1, 2, 3, ..., n \tag{6}$$

$$C_{0,j} = 0 \quad \forall j = 1, 2, 3, ...., n \tag{7}$$

$$C_{i,0} = 0 \quad \forall i = 1, 2, 3, ...., m \tag{8}$$

$$Y_{j,k} \varepsilon \{0, 1\} \quad \forall j, k = 1, 2, 3, ....n. \tag{9}$$

In this formulation, the weighted sum of makespan and system utilization time is to be minimized. Here the weight $w1\ \varepsilon$ [0, 1]. For $w1 > 0.5$, more weight is given to the criteria of makespan while more weight is given to system utilization time for $w1 < 0.5$. In our problem we have given equal weights to both the criteria.

Due to constraint (2) the makespan is the maximum completion time of all the jobs on system of machines. Constraint (3) and (4), establish the relation between current completion time and occurred completion time. Constraint (5) ensures the schedule is permutation schedule. Constraint (6) ensures that exactly one job *j* among all the jobs is assigned the position *k* in sequence $\sigma$ during processing. Constraint (7)-(9) depicts the domain of decision variables.

## 3. HEURISTIC METHODS

Flow shop scheduling problem with sequence dependent setup time is NP-hard (Gupta (1986)). Therefore, it is always prefer- able to solve the problems with approximate methods rather than exact methods. In this paper three significant heuristic methods *H*1, *H*2, *H*3 has been developed to solve the referred problem. The complete procedure of these methods is given as:

**Step 1** Obtain the initial feasible schedule $\pi$ .

**Step 2** Consider first two jobs from schedule $\pi$ and arrange them corresponding to minimum weighted sum of makespan and system utilization time. Obtain partial optimal schedule $\sigma$ with length $L = 2$.

**Step 3** Consider the next job from schedule $\pi$ and insert at all the available positions of $\sigma$ . Obtain the optimal partial sequence of length $L = L + 1$.

**Step 4** Repeat step 3 until $L = n$ and optimal schedule of all the jobs is obtained.

**Step 1** in significant heuristics *H*1, *H*2, *H*3, are obtained by using descending order of total processing time, descending order of sum of average processing time and standard deviation of processing time and descending order of sum of average, standard deviation, skewness and inverse of kurtosis of processing time respectively.

Further, to get better results of objective function the latest time has been introduced on system of machines as:

- **Result 1** The processing on the machine *m* to be delayed by $d_m = \sum_{j=1}^{n} IT_{m,j}$ results in minimum value of objective function without violating the makespan for schedule $\sigma$ .
- **Result 2** Delaying the processing of jobs on machine $'i'$ , $\forall i = m-1, m-2, ..., 2$, by $d_i = min(d_{i,j} | d_{i,j} \geqslant C_{(i-1),1}, \forall j = 1, 2, 3, ..., n)$ keeps makespan unaltered, whereas total utiliza- tion time and hence the objective function is lesser. Where,

(a) $d_{i,1} = d_{i+1} - p_{i,1}$ &

(b) $d_{i,j} = d_{i+1} + \sum_{k=1}^{j-1} p_{i+1,j} + \sum_{k=2}^{j} S_{(k-1)k,(i+1)} - \sum_{k=1}^{j} p_{i,k} - \sum_{k=2}^{j} S_{(k-1)k,i} \; 2, 3, 4, ...., n.$

## 4. COMPUTATION ANALYSIS

To test the effectiveness of proposed heuristics *H*1, *H*2, *H*3, to solve the referred problem of flow shop environment the results has been compared for system of uniformly generated varying machine job environment against the existing classical heuristics *NEH* (Nawaz et.al.(1984)), *NEHD* (Dong et.al.(2008)). For the comparison purpose all the referred heuristics are coded in MATLAB environment and run over Intel(R) core (TM) i5 CPU @2.20GHZ computer with RAM 8 GB. Sequence dependent setup time is generated following uniform distribution ranging as: [1,24], [1,49] and [1,99]. Equal weights are given to both system utilization time and makespan. Experi- mental set for the referred heuristics is given in table 2.

**Table 2: Experimental parameters and their magnitudes**

| Parameters | values |
|---|---|
| $w1$ | 0.5 |
| $p_{i,j}$ | $U$ [1, 99] |
| $S_{i,jk}$ | $U$ [1, 24], $U$ [1, 49], $U$ [1, 99] |
| $n$ | 10, 15, 20, 30 |
| $m$ | 3, 5, 7, 10 |
| Number of instances | 10 |
| Number of solution problems | 1 × 3 × 4 × 4 × 10 = 480 |

To compare the efficiency of proposed heuristics in solving considered problem over the referred heuristics the average relative percentage deviation (ARPD) is calculated as:

$$ARPD = \sum \frac{\text{(Heuristic solution-Best Solution)} \times 100}{\text{Best Solution}}$$

Best solution is the solution the best approximate solution during the experiment over the particular machine job environment. Here summation varies over all the problem instances of particular ma- chine job environment. The results obtained has been shown in figures 1-3

Figure 1: **ARPD of heuristics for setup time is** $U[1, 24]$

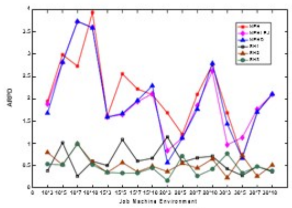


Figure 2: **ARPD of heuristics for setup time is** $U[1, 99]$

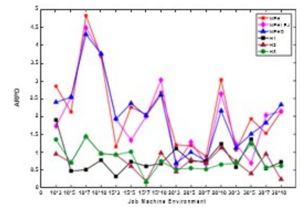
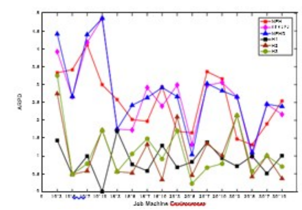


Figure 3: **ARPD of heuristics for setup time is** $U[1, 99]$



From figure 1 specified heuristic *H*3 gives best result for 12 out of 16 different problem instances for setup time is 25% of processing time that is its range is $U[1, 24]$ whereas for the same problem instances *H*2 gives second best and *H*1 gives third best solutions. From figure 2 for the problem instances with setup time is 50% of processing time i.e. range is $U[1, 49]$ heuristic *H*1 gives best solution for small size instances while *H*3 gives the best solution for large size problem instances. For problem instances with setup time is $U[1, 99]$ the heuristic *SH*1 is best for 6 problem instances, *H*2 is giving the best values of *ARPD* for 10 problem instances. Overall results depict that *H*3 is the best heuristic among all the proposed heuristics to solve the referred problem whereas *H*1 is second best to solve the referred problem.

## 5. CONCLUSION

Flow shop scheduling problem with sequence dependent setup time has been introduced in this paper. The objective is to sched- ule the jobs over the available system of machines such that weighted sum of makespan and system utilization time is minimum. Since both makespan and system utilization time depends on idle time.

Makespan depends on idle time of last machine whereas the sys- tem utilization depends on system idle time. To reduce the value of objective function further latest time $d_i$ has been introduced for each of machine *i*.

To solve the large size flow shop scheduling problem with both referred criteria three specific heuristics has been developed. The proposed heuristics with delay time has been compared with ex- isting classical heuristics and results depict that proposed heuristics are more effective to solve the referred problem than existing heuristics.

Considering other criteria of scheduling like tardiness, number of tardy jobs, transportation cost under sequence dependent setup time is possible extension of referred problem.

**Acknowledgment** One of authors acknowledges the financial sup- port provided by council of scientific and industrial research, New Delhi, India, in the form of JRF through grant number 09/135(0766)/2017- EMR-I.

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