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ON SPECIALLY STRUCTURED TWO STAGE FLOW SHOP SCHEDULING PROBLEM WITH SETUP TIME SEPARATED FROM PROCESSING TIME AND JOBS IN A STRING OF DISJOINT JOB BLOCKS

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ABSTRACT

This paper relates to two stage specially structured flow shop scheduling problem with jobs in a string of disjoint job blocks having sequence independent setup times separated from processing times each associated with their respective probabilities, where the optimization criteria is the utilization time of machines. To minimize the utilization time an algorithm is proposed and a numerical example is given to validate the algorithm.

Keywords: Disjoint Job Blocks, Equivalent job, Jobs in a String, Processing time, Setup Time Specially Structured Flow Shop Scheduling, Utilization Time.

I INTRODUCTION

In a classical job shop scheduling problem n-jobs are processed on m-machines and the order of processing each job through machines is given. Each machine can process one operation at a time and pre-emption of jobs is not allowed. The common objectives in job shop scheduling problems are to minimize some performance measures such as makespan, mean flow time, mean tardiness, mean setup time, number of tardy jobs and mean number of setups. Production scheduling is a form of decision making that plays an important role in manufacturing industries and service sectors. In manufacturing system, the scheduling means allocation of a set of jobs on a set of production resources over time to optimize some objective. Johnson [1] developed an algorithm for two stage production schedule for minimizing the makespan. Smith [2] considered minimization of mean flow time and maximum tardiness. Palmer [3] gave a heuristic algorithm for sequencing jobs to minimize the total elapsed time.

Setup time includes the time to prepare the machines, obtaining, adjusting and returning tools for an operation, cleaning up the machines, setting the necessary jigs and fixtures and inspecting and positioning the process material. Setup time has an important part as reduction in setup time leads to increase in output, profitability and

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customer satisfaction in an organization. The setup times in scheduling problems can be classified into two categories: the first category of setup times is known as sequence-independent setup times and second category involves setup times depending upon sequence of jobs to be processed on machines and is termed as sequence-dependent setup times. Sequence-independent setup time depends solely on current task regardless of its previous task, for example a machine shop performing simple machining operations. Sequence dependent setup time depends on both current and immediately preceding task. Yoshida and Hitomi [4] considered two stage production scheduling problem with set up time. Allahverdi et al. [5] surveyed the literature of scheduling problems involving set up time till 1999. The literature involving set up time up to 2006 is again reviewed by Allahverdi et al. [6]. Gupta, S. Bala & Singla [7] gave an algorithm to minimize rental cost for specially structured two stage flow shop scheduling problem including setup time and weightage of jobs. A comprehensive review of the literature on job shop scheduling research involving setup times is given by Sharma and Jain [8].

The concept of job block is significant in scheduling systems where certain orderings of jobs are prescribed either by technological constraints or by externally imposed policy. The basic concept of equivalent job for job block in job sequencing was investigated by Maggu and Das [9]. Gupta et al. [10] studied two stage flow shop scheduling, setup times separated from processing times including job block criteria and considering interval of non-availability of machines using branch and bound technique.

The string of disjoint job blocks consist of two disjoint job blocks such that in one job block the order of jobs is fixed and in second job block the order of jobs is arbitrary. Anup and Maggu [11] gave an optimal schedule for n×2 flow shop problem with job blocks of jobs in which first job in each job block being the same. Heydari [12] studied flow shop scheduling problem with processing of jobs in a string of disjoint job blocks. Singh, Kumar, and Gupta [13] studied n×2 flow-shop scheduling problem in which processing time, set up time each associated with probabilities along with jobs in a string of disjoint job blocks. Gupta, Sharma and Gulati [14] studied n×3 flow shop scheduling problem in which processing time, set up time each associated with probabilities along with jobs in a string of disjoint job blocks.

In this paper n×2 specially structured flow shop scheduling problem with sequence independent setup times separated from processing times each associated with probabilities and jobs in a string of disjoint job block is considered. The objective of the study is to obtain an optimal sequence of jobs to minimize the utilization time of the machines. To solve the problem an algorithm is proposed.

II PRACTICAL SITUATION

In our day to day functioning in service centres and factories many applied and experimental situations exist regarding flow shop scheduling. For optimal utilization of available resources there must be a proper scheduling system and this makes scheduling a highly important aspect of industrial units. Two machine specially structured flowshop scheduling problem has been considered as there are many practical situations where the processing times are not random but follow well defined structural relationship to one another. For example, in textile industry different types of fabric are produced using different types of yarn. Here, the time taken in dying of yarn on first machine is always less than the weaving of yarn on the second machine.

The idea of job block has practical significance to create a balance between the cost of providing priority in service to the customer and cost of giving service with non priority. Thus, the job block represents the relative importance and group binding of jobs. Example of jobs in a string of disjoint job block occurs in steel manufacturing industries where certain jobs such as heating and molding must be carried out as a fixed job block in processing and other jobs such as cutting, grinding, chroming etc. can be processed in a block disjoint from the first block in an optimal order to minimize the makespan. In many practical situations, setup time is required while shifting from one operation to another. Setup time affects the optimization criteria in scheduling problems and so it is needed to be considered separately from processing time.

III NOTATIONS

The following notations have been used throughout the paper:

σ: Sequence of n- jobs obtained by applying Johnson's algorithm.

σ_k: Sequence of jobs obtained by applying the proposed algorithm, k = 1, 2, 3, ------.

M_j: Machine j, j= 1, 2.

a_{ij}: Processing time of i^{th} job on machine M_j.

s_{ij}: Set up time of i^{th} job on machine M_j.

p_{ij}: Probability associated to the processing time a_{ij}.

q_{ij}: Probability associated to the set up time s_{ij}.

A_{ij}: Expected processing time of i^{th} job on machine M_j.

S_{ij}: Expected set up time of i^{th} job on machine M_j.

$t_{ij}(\sigma_k)$: Completion time of i^{th} job of sequence σ_k on machine M_j.

$T(\sigma_k)$: Total elapsed time for jobs 1, 2, --------, n for sequence σ_k.

$I_{ij}(\sigma_k)$: Idle time of machine M_j for job i in the sequence σ_k.

$U_j(\sigma_k)$: Utilization time for which machine M_j is required for sequence σ_k.

$A_{ij}(\sigma_k)$: Expected processing time of i^{th} job on machine M_j for sequence σ_k.

α: Fix order job block.

β: Job block with arbitrary order.

β_k: Job block with jobs in an optimal order obtained by applying the proposed algorithm, k = 1, 2, 3, ------.

S: String of job blocks α and β i.e. S = (α, β)

S′: Optimal string of job blocks α and β_k.

IV ASSUMPTIONS

The assumptions for the proposed algorithm are stated below:

a) Jobs are independent to each other. Let n jobs be processed thorough two machines M_1 and M_2 in order M_1 M_2.
b) Machine breakdown is not considered.
c) Pre-emption is not allowed. Once a job is started on a machine the process on that machine cannot be stopped unless the job is completed.

d) Expected flow times A'_{i1} and A'_{j2} for jobs i and j must satisfy the structural conditions viz. $A'_{i1} \geq A'_{j2}$ or $A'_{i1} \leq A'_{j2}$ for each i and j.

e) Each job has two operations and each job is processed through each of the machine once and only once.

f) Each machine can perform only one task at a time.

g) A job is not available to the next machine until and unless processing on the current machine is completed.

h) The independency of processing times of jobs on the schedule is maintained.

i) Only one machine of each type is available.

j) $\sum_{i=1}^{n} p_{ij} = 1,\ \sum_{i=1}^{n} q_{ij} = 1,\ 0 \leq p_{ij}, q_{ij} \leq 1$

k) Jobs i_1, i_2, ---------------, i_h are to be processed as a job block (i_1, i_2, ----------------, i_h) showing priority of job i_1 over i_2 etc. in that order in case of a fixed order job block.

V DEFINITION

Completion time of i^{th} job on machine M_j is given by,

$$t_{ij} = max\,(t_{i-1,j} + S_{i-1,j}\,, t_{i,j-1}\,) + A_{ij}\ ;\ j \geq 2,$$

where A_{ij} = Expected processing time of i^{th} job on machine M_j and S_{ij} = Expected set up time of i^{th} job on machine M_j.

VI PROBLEM FORMULATION

Let n- jobs (i = 1, 2, ------, n) be processed on two machines M_j (j = 1, 2) in the order M_1M_2. Let a_{ij} be the processing time and s_{ij} be the setup time of i^{th} job on j^{th} machine with probabilities p_{ij} and q_{ij} respectively such that $0 \leq p_{ij} \leq 1$, $\sum_{i=1}^{n} p_{ij} = 1$, $0 \leq q_{ij} \leq 1$, $\sum_{i=1}^{n} q_{ij} = 1$. Let A_{ij} & S_{ij} be the expected processing time and set up time respectively of i^{th} job on j^{th} machine. The mathematical model of the problem in matrix form can be stated as:

Table -1

Jobs	Machine M_1				Machine M_2			
i	a_{i1}	p_{i1}	s_{i1}	q_{i1}	a_{i2}	p_{i2}	s_{i2}	q_{i2}
1	a_{11}	p_{11}	s_{11}	q_{11}	a_{12}	p_{12}	s_{12}	q_{12}
2	a_{21}	p_{21}	s_{21}	q_{21}	a_{22}	p_{22}	s_{22}	q_{22}
3	a_{31}	p_{31}	s_{31}	q_{31}	a_{32}	p_{32}	s_{32}	q_{32}
-	-	-	-	-	-	-	-	-
n	a_{n1}	p_{n1}	s_{n1}	q_{n1}	a_{n2}	p_{n2}	s_{n2}	q_{n2}

Consider two job blocks α and β such that the job block α consist of s jobs with fixed order of jobs and β consist of r jobs in which order of jobs is arbitrary such that s + r = n and $\alpha \cap \beta = \emptyset$ i.e. the two job blocks α and β form a disjoint set in the sense that the two blocks have no job in common. Let S = (α, β). Our aim is to find job block β_k with jobs in an optimal order and an optimal string S' of job blocks α and β_k i.e. to find a sequence σ_k of jobs which minimizes the utilization times of machines given that S = (α, β).

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Mathematically, the problem is stated as:

Minimize T (σ_k) and hence

Minimize U_2 (σ_k), given that S = (α, β).

VII PROPOSED ALGORITHM

Step 1: Calculate the expected processing times A_{ij} given by $A_{ij} = a_{ij} \times p_{ij}$.

Step 2: Compute the expected flow times A'_{i1} and A'_{i2} for respective machines M_1 and M_2 as:

$$A'_{i1} = A_{i1} - S_{i2}, \text{ and}$$

$$A'_{i2} = A_{i2} - S_{i1}.$$

Step 3: For any equivalent job α (say) for the job block (r, m) we calculate the expected flow time $A'_{\alpha 1}$ and $A'_{\alpha 2}$ on the guidelines of Maggu and Das [1977] as follows:

$$A'_{\alpha 1} = A'_{r1} + A'_{m1} - \min (A'_{m1}, A'_{r2})$$

$$A'_{\alpha 2} = A'_{r2} + A'_{m2} - \min (A'_{m1}, A'_{r2})$$

If a job block has three or more than three jobs then to find the expected flow times we use the property that the equivalent job for job-block is associative i.e. $((i_1, i_2), i_3) = (i_1, (i_2, i_3))$.

Step 4: Check the structural conditions that $A'_{i1} \geq A'_{j2}$ or $A'_{i1} \leq A'_{j2}$ for each i and j obtained in Step 2. If the structural conditions hold good obtain the new job block β_k having jobs in an optimal order from the job block β (disjoint from job block α) by treating job block β as sub flow shop scheduling problem of the main problem. For finding β_k follow the following steps:

(A): Obtain the job J_1 (say) having maximum expected flow time on 1st machine and job J_r (say) having minimum expected flow time on 2nd machine. If $J_1 \neq J_r$ then put J_1 on the first position and J_r at the last position and go to 4(C) otherwise go to 4(B).

(B): Take the difference of expected flow time of job J_1 on M_1 from job J_2 (say) having next maximum expected flow time on machine M_1. Call this difference as G_1. Also take the difference of expected flow time of job J_r on machine M_2 from job J_{r-1} (say) having next minimum expected flow time on M_2. Call this difference as G_2. If $G_1 \leq G_2$ then put J_r on the last position and J_2 on the first position otherwise put J_1 on 1st position and J_{r-1} on the last position. Now follow step 4(C).

(C): Arrange the remaining (r − 2) jobs, if any between 1st job J_1 (or J_2) & last job J_r (or J_{r-1}) in any order; thereby due to structural conditions we get the job blocks $\beta_1, \beta_2 \ldots \beta_m$ with jobs in optimal order and each having same elapsed time. Let $\beta_k = \beta_1$ (say).

Obtain the expected flow times $A'_{\beta_k 1}$ and $A'_{\beta_k 2}$ for the job block β_k as defined in step 3.

Step 5: Now reduce the given problem to a new problem by replacing s-jobs by job block α with expected flow times $A'_{\alpha 1}$ and $A'_{\alpha 2}$ and remaining r-jobs by a disjoint job block β_k with expected flow times $A'_{\beta_k 1}$ and $A'_{\beta_k 2}$. The new reduced problem can be represented as:

Table: 2

Jobs	Machine M_1	Machine M_2
i	A'_{i1}	A'_{i2}
α	$A'_{\alpha 1}$	$A'_{\alpha 2}$
β_k	$A'_{\beta_k 1}$	$A'_{\beta_k 2}$

Step 6: Check the structural conditions: $A'_{i1} \geq A'_{j2}$ or $A'_{i1} \leq A'_{j2}$ for each i and j. If the structural conditions hold good go to Step 7 to find S′ otherwise modify the problem.

Step 7: For finding optimal string S′ follow the following steps:

(*a*) Obtain the job I_1 (say) having maximum expected flow time on 1st machine and job I'_1 (say) having minimum expected flow time on 2nd machine. If $I_1 \neq I'_1$ then put I_1 on the first position and I'_1 at last position to obtain S′ otherwise go to 7 (b).

(b) Take the difference of expected flow time of job I_1 on M_1 from job I_2 (say) having next maximum expected flow time on machine M_1. Call this difference as H_1. Also take the difference of expected time of job I'_1 on machine M_2 from job I'_2 (say) having next minimum expected flow time on M_2. Call this difference as H_2. If $H_1 \leq H_2$ then put I'_1 on the second position and I_2 at the first position otherwise put I_1 on first position and I'_2 at the second position to obtain the optimal string S′.

Step 8: Compute the in - out table for sequence σ_k of jobs in the optimal string S′.

Step 9: Compute the total elapsed time T (σ_k).

Step 10: Calculate the utilization time U_2 (σ_k) of 2nd machine given by

$$U_2(\sigma_k) = T(\sigma_k) - A_{11}(\sigma_k).$$

VIII NUMERICAL ILLUSTRATION

To minimize the utilization time and rental cost for six jobs to be processed in a string S of disjoint blocks on two machines as job block α = (1, 3) with fixed order of jobs and job block β = (2, 4, 5, 6) with arbitrary order of jobs such that $\alpha \cap \beta = \emptyset$. The processing times and setup times with respective probabilities are given in the following TABLE:

Table: 3

Jobs	Machine M_1				Machine M_2			
i	a_{i1}	p_{i1}	s_{i1}	q_{i1}	a_{i2}	p_{i2}	s_{i2}	q_{i2}
1	33	0.2	2	0.1	11	0.2	5	0.2
2	34	0.1	3	0.3	9	0.3	4	0.1
3	27	0.2	6	0.2	16	0.1	4	0.2
4	24	0.2	3	0.2	13	0.1	5	0.3
5	26	0.2	7	0.1	8	0.2	2	0.1
6	36	0.1	3	0.1	9	0.1	2	0.1

Solution: As per step 1: The expected processing times and expected setup times for machines M_1 and M_2 are as follow:

Table: 4

Jobs	Machine M_1		Machine M_2	
i	A_{i1}	S_{i1}	A_{i2}	S_{i2}
1	6.6	0.2	2.2	1.0
2	3.4	0.9	2.7	0.4
3	5.4	1.2	1.6	0.8
4	4.8	0.6	1.3	1.5
5	5.2	0.7	1.6	0.2
6	3.6	0.3	0.9	0.2

As per step 2: The expected flow times for machines M_1 and M_2 are as follow:

Table: 5

Jobs	Machine M_1	Machine M_2
i	A'_{i1}	A'_{i2}
1	5.6	2.0
2	3.0	1.8
3	4.6	0.4
4	3.3	0.7
5	5.0	0.9
6	3.4	0.6

As per step 3: Expected flow times $A'_{\alpha1}$ and $A'_{\alpha2}$ for the equivalent job block $\alpha = (1, 3)$ are calculated as:

$$A'_{\alpha1} = A'_{r1} + A'_{m1} - \min(A'_{m1}, A'_{r2}) \qquad \text{(Here r=1 \& m=3)}$$
$$= 5.6 + 4.6 - \min(4.6, 2.0)$$
$$= 10.2 - 2.0 = 8.2$$
$$A'_{\alpha2} = A'_{r2} + A'_{m2} - \min(A'_{m1}, A'_{r2})$$
$$= 2.0 + 0.4 - \min(4.6, 2.0)$$
$$= 2.4 - 2.0 = 0.4$$

As per step 4: We have $A'_{i1} \geq A'_{j2}$ for each i and j as computed in step 2. So using step 4 we get
$\beta_k = (5, 2, 4, 6)$.

Now, we know that the equivalent job for job-block is associative i.e. $((i_1, i_2), i_3) = (i_1, (i_2, i_3))$ and so we have,
$\beta_k = (5, 2, 4, 6) = ((5, 2), 4, 6) = (\alpha_1, 4, 6) = (\alpha_2, 6)$, where $\alpha_1 = (5, 2)$ and $\alpha_2 = (\alpha_1, 4)$

Therefore, we have

$$A'_{\alpha_1 1} = 5.0 + 3.0 - \min(3.0, 0.9) = 8.0 - 0.9 = 7.1$$
$$A'_{\alpha_1 2} = 0.9 + 1.8 - \min(3.0, 0.9) = 2.7 - 0.9 = 1.8$$

$A'_{\alpha_2 1}$ = 7.1 + 3.3 – min (3.3, 1.8) = 10.4 – 1.8 = 8.6

$A'_{\alpha_2 2}$= 1.8 + 0.7 – min (3.3, 1.8) = 2.5 – 1.8 = 0.7

$A'_{\beta_k 1}$ = 8.6 + 3.4 – min (3.4, 0.7) = 12.0 – 0.7 = 11.3

$A'_{\beta_k 2}$= 0.7 + 0.6 – min (3.4, 0.7) = 1.3 – 0.7 = 0.6

As per step 5: The reduced problem is defined below:

Table: 6

Jobs	Machine M_1	Machine M_2
i	A'_{i1}	A'_{i2}
α	8.2	0.4
β_k	11.3	0.6

Here, $A'_{i1} \geq A'_{j2}$ for each i and j, and thus the structural relations hold good.

As per step 7 the max_i $\{A'_{i1}\}$ = 11.3 is for job β_k i.e. $I_1 = \beta_k$ and min_i $\{A'_{i2}\}$ = 0.4 is for job α i.e. I'_1 = α. Since $I_1 \neq I'_1$, so we put $I_1 = \beta_k$ on the first position and I'_1 = α on the second position.

Therefore, the optimal string S′ as per step 7 is given by S′ = (β_k, α).

Hence, the optimal sequence σ_k of jobs as per string S′ is σ_k = 5 – 2 − 4 – 6 − 1 – 3.

The in-out table for optimal sequence σ_k is:

Table: 7

Jobs	Machine M_1	Machine M_2
i	In-Out	In-Out
5	0.0 − 5.2	5.2 − 6.8
2	5.9 − 9.3	9.3 − 12.0
4	10.2 − 15.0	15.0 − 16.3
6	15.6 − 19.2	19.2 − 20.1
1	19.5 − 26.1	26.1 − 28.3
3	26.3 – 31.7	31.7 – 33.3

Therefore, the total elapsed time = T (σ_k) = 33.3 units.

Utilization time of machine M_2 = U_2 (σ_k) = (33.3 – 5.2) units.

= 28.1 units.

IX REMARKS

If we solve the same problem by Johnson's [1] method by treating job block β as sub flow shop scheduling problem of the main problem we get the new job block β′ from the job block β (disjoint from job block α) as β′ = (2, 5, 4, 6).

The expected flow time $A'_{\beta' 1}$ and $A'_{\beta' 2}$ for the job block β′ on the guidelines of Maggu and Das [1977] are calculated below:

We have, β′ = (2, 5, 4, 6).

Now, β′ = (2, 5, 4, 6) = ((2, 5), 4, 6) = (α′, 4, 6) = (γ, 6); where α′ = (2, 5) and γ = (α′, 4).

$A'_{\alpha'1}$ = 3.0 + 5.0 – min (5.0, 1.8) = 8.0 – 1.8 = 6.2.

$A'_{\alpha'2}$ = 1.8 + 0.9 – min (5.0, 1.8) = 2.7 – 1.8 = 0.9.

$A'_{\gamma1}$ = 6.2 + 3.3 – min (3.3, 0.9) = 9.5 – 0.9 = 8.6.

$A'_{\gamma2}$ = 0.9 + 0.7 – min (3.3, 0.9) = 1.6 – 0.9 = 0.7.

$A'_{\beta'1}$ = 8.6 + 3.4 – min (3.4, 0.7) = 12.0 – 0.7 =11.3.

$A'_{\beta'2}$ = 0.7 + 0.6 – min (3.4, 0.7) = 1.3 – 0.7 = 0.6.

The reduced problem is defined below:

Table: 8

Jobs	Machine M_1	Machine M_2
i	A'_{i1}	A'_{i2}
α	8.2	0.4
β′	11.3	0.6

By Johnson's [1] algorithm the optimal string S′ is given by S′ = (β′, α).

Therefore, the optimal sequence σ for the original problem corresponding to optimal string S′ is given by $\sigma = 2 – 5 – 4 – 6 − 1 – 3$.

The in – out flow table for the optimal sequence σ is:

Table: 9

Jobs	Machine M_1	Machine M_2
i	In - Out	In - Out
2	0.0 − 3.4	3.4 − 6.1
5	4.3 − 9.5	9.5 − 11.1
4	10.2 − 15.0	15.0 − 16.3
6	15.6 − 19.2	19.2 − 20.1
1	19.5 − 26.1	26.1 − 28.3
3	26.3 – 31.7	31.7 – 33.3

Therefore, the total elapsed time = T (σ) = 33.3 units.

Utilization time of machine M_2 = $U_2(\sigma)$ = (33.3− 3.4) units.

= 29.9 units.

X CONCLUSION

From TABLE: 9 we see that the utilization time of machine M_2 is $U_2(\sigma)$ = 29.9 units with makespan of 33.3 units. However, if the proposed algorithm is applied the utilization time of machine M_2 as per TABLE: 7 is $U_2(\sigma_k)$ = 28.1 units with the same makespan of 33.3 units. Hence, the proposed algorithm is more efficient as it optimizes both the makespan and the utilization time simultaneously for a specially structured two stage flow shop scheduling problem as compared to the algorithm proposed by Johnson [1].

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