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Minimization of Utilization Time for Specially Structured n × 3 Scheduling Model with Jobs in a String of Disjoint Job Blocks

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***Abstract:** The present paper investigates n×3 specially structured flow shop scheduling model with processing of jobs on given machines in a string of disjoint job blocks and with probabilities associated to the processing times of jobs. The objective is to minimize utilization time of second and third machine and also minimize the total elapsed time for processing the jobs for n×3 specially structured flow shop scheduling problem. The algorithm developed in this paper is quite straightforward and easy to understand and also present an essential way out to the decision maker for attaining an optimal sequence of jobs. The algorithm developed in this paper is validated by a numerical illustration.*

***Keywords:** Disjoint Job Blocks, Elapsed Time, Jobs in a String, Specially Structured Flow Shop Scheduling, Utilization Time.*

I. INTRODUCTION

Scheduling means to determine a sequence of jobs for a set of machines such that certain performance measures are optimized. Scheduling is generally considered to be one of the most important issues in the planning and operation of a manufacturing system. Better scheduling system has vital influence in decreasing the cost, increasing the output, client contentment and on the whole provides competitive assistance to the organisation. Scheduling leads to increase in capacity utilization, improves efficiency and thereby reduces the time required to complete the jobs and consequently increases the profitability of an organisation in today's global state of affairs. Manufacturing units and service centres play an important part in the economic growth of a nation. Productivity can be increased if the existing assets are used in an optimal method. In the routine working of production houses and service providers numerous applied and experimental situations exist relating to flow shop scheduling. In general flow shop scheduling problem, n-jobs has to be passed in succession for processing on m-machines in some specific order in which passing of jobs on machines is not allowed.

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Johnson [1] developed the heuristic algorithm for two and three stage scheduling problems for optimizing the makespan. The usual n-job and m- machine scheduling problem was explained by Smith and Dudek [2].
Cambell et al. [3] proposed the generalization of Johnson's method by developing artificial two machine problems from the original m-machine problem and solved them using Johnson's algorithm. Specially structured flow shop scheduling was studied by Gupta, J.N.D. [4] to develop an algorithm for finding an optimal schedule of jobs. Specially structured two stage flow shop model was explained by Gupta, D., Sharma, S. and Bala, S. [9] to reduce the rental cost of machines by considering pre-defined rental policy. Maggu, P. L. and Das, G. [5] gave the fundamental idea of equivalent job for job block in sequencing problems. Singh, T.P., Kumar, R. & Gupta, D. [7] gave a heuristic approach to minimize production cost in case of three machines by considering job block criteria and associating probabilities to both the processing time and set up times. Heydari [6] studied flow shop scheduling problem by processing the jobs on machines in a string of disjoint job blocks. The string of disjoint job blocks is comprised of two disjoint job blocks with one job block having the jobs in a predetermined order and in second job block the jobs are in random order. Gupta, D., Sharma, S. and Gulati, N. [8] studied three machine scheduling problem in which processing time, set up time each associated with probabilities along with jobs processed on machines as string of disjoint job blocks. Gupta, D., Sharma, S. and Aggarwal, S. [10] studied flow-shop scheduling with jobs processed on machines as string of disjoint job blocks. Gupta, D. et al. [11] studied 3-stage specially structured flow shop scheduling to minimize the rental cost of machines including transportation time, weightage of jobs and job block criteria.
In this paper we consider n×3 specially structured flow shop scheduling model with jobs processed on given machines in a string of disjoint job blocks. The objective of this paper is to develop a heuristic algorithm to find the optimal sequence of jobs to minimize the elapsed time and the utilization time of machines in case of specially structured n×3 flow shop scheduling problem with jobs processed on given machines in a string of disjoint job blocks.

II. PRACTICAL SITUATION

Industries and service centers have an essential role in the economic development of a country. Production can be maximized if the available resources are utilized in an optimal manner.

For optimal utilization of available resources there must be a proper scheduling system for the resources and this makes scheduling a highly important aspect of manufacturing systems. It can be seen that in the daily working of industrial units, service centers and business establishment different jobs are processed on various machines and as such the optimization of certain parameters through scheduling has an essential role to play. Specially structured flow-shop scheduling problem has been taken up owing to its significance in actual functioning of scheduling models as there are many situations where the time taken for the processing of jobs on machines does not take arbitrary values but they have some definite structural relationships with one another.

III. NOTATIONS

We use the following notations in this paper:

σ: Sequence of jobs acquired by using Johnson's method.

σ_k: Sequence of jobs acquired by using the algorithm developed in this paper.

M_j: Machine j.

$\tilde{a}_{ij}$: Time taken for processing the job i on machine j.

$\tilde{p}_{ij}$: Probability attached to $\tilde{a}_{ij}$.

A_{ij}: Expected time of processing of job i on machine j.

t_{ij} (σ_k): Completion time of job i of sequence σ_k on machine j.

T (σ_k): Total elapsed time for processing the jobs in sequence σ_k.

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

A_{ij} (σ_k): Expected time of processing of job i on machine j for sequence σ_k.

α: Job block having fix order of jobs.

β: Job block having random order of jobs.

β_k: Job block having jobs in an optimal order acquired by using the algorithm developed in this paper.

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

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

IV. MODEL ASSUMPTIONS

The assumptions regarding the jobs and machines are given below:

a) Jobs are not dependent on one another and are processed on three machines M_1, M_2 and M_3 in order $M_1M_2M_3$.

b) Pre-emption is not considered. Once the processing of a job is commenced on a machine it cannot be stopped unless the processing of this job is concluded.

c) Each job has to be processed on all machines. Each job is processed on a machine only once.

d) In case of processing of jobs in a fixed order job block (i_1, i_2, ------, i_h) the job i_1 has preference over job i_2 etc. in that order.

e) Expected processing times must obey the relationships: $\min_i\{A_{i1}\} \geq \max_i\{A_{i2}\}$ or $\min_i\{A_{i3}\} \geq \max_i\{A_{i2}\}$.

f) Processing times G_i and H_i for fictitious machines G and H must obey the requirements: $\min_i\{G_i\} \geq \max_i\{H_i\}$ or $\max_i\{G_i\} \leq \min_i\{H_i\}$.

V. DEFINITION

Utilization time U_2 of machine M_2 and U_3 of machine M_3 for sequence σ_k is respectively defined as:

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

$U_3(\sigma_k) = T(\sigma_k) - A_{11}(\sigma_k) - A_{12}(\sigma_k)$.

VI. PROBLEM FORMULATION

Let us schedule n-jobs on given machines M_1, M_2 and M_3 in the order $M_1 \rightarrow M_2 \rightarrow M_3$. Let $\tilde{a}_{ij}$ denote the processing time of job *i* on the machine *j* with probability $\tilde{p}_{ij}$ such that $0 \leq \tilde{p}_{ij} \leq 1$ and $\sum_{i=1}^{n} \tilde{p}_{ij} = 1$. Consider the job blocks α and β with job block α comprising of s-jobs having prearranged order of jobs and β comprising of p-jobs having jobs in random order such that s + p = n and $\alpha \cap \beta = \emptyset$. The two job blocks α and β are disjoint having no job in common. Let S = (α, β). The processing time of the jobs are given in the table-I below:

Table – I: Model Formulation

Jobs	Machine M_1		Machine M_2		Machine M_3	
i	$\tilde{a}_{i1}$	$\tilde{p}_{i1}$	$\tilde{a}_{i2}$	$\tilde{p}_{i2}$	$\tilde{a}_{i3}$	$\tilde{p}_{i3}$
1	$\tilde{a}_{11}$	$\tilde{p}_{11}$	$\tilde{a}_{12}$	$\tilde{p}_{12}$	$\tilde{a}_{13}$	$\tilde{p}_{13}$
2	$\tilde{a}_{21}$	$\tilde{p}_{21}$	$\tilde{a}_{22}$	$\tilde{p}_{22}$	$\tilde{a}_{23}$	$\tilde{p}_{23}$
3	$\tilde{a}_{31}$	$\tilde{p}_{31}$	$\tilde{a}_{32}$	$\tilde{p}_{32}$	$\tilde{a}_{33}$	$\tilde{p}_{33}$
-	-	-	-	-	-	-
n	$\tilde{a}_{n1}$	$\tilde{p}_{n1}$	$\tilde{a}_{n2}$	$\tilde{p}_{n2}$	$\tilde{a}_{n3}$	$\tilde{p}_{n3}$

Our objective is to find an optimal job block β_k and hence to find the string S′ having job blocks α and β_k in an optimal order. Thus, we need to find a sequence σ_k of jobs that minimizes the elapsed time and the utilization times of machine with processing of jobs on machines in a string of disjoint job blocks. Mathematically, the problem is stated as: Minimize T (σ_k), U_2 (σ_k) and U_3 (σ_k); where S = (α, β).

VII. HEURISTIC ALGORITHM

Step 1: Compute the expected times of processing $A_{ij} = \tilde{a}_{ij} \times \tilde{p}_{ij}$.

Step 2: Make sure that the requirements $\min_i\{A_{i1}\} \geq \max_i\{A_{i2}\}$ or $\min_i\{A_{i3}\} \geq \max_i\{A_{i2}\}$ are satisfied. If these requirements are fulfilled go to step 3, if not then redefine the problem.

Step 3: Let G and H be two fictitious machines with processing times G_i and H_i respectively given by:

$$G_i = A_{i1} + A_{i2} \text{ and } H_i = A_{i2} + A_{i3}$$

Step 4: Verify that $\min_i\{G_i\} \geq \max_i\{H_i\}$ or $\max_i\{G_i\} \leq \min_i\{H_i\}$.

Step 5: For the equivalent job α corresponding to the job block say, (r, m) compute the time G_α and H_α taken for processing of this job α as given by Maggu and Das [5]:

$$G_\alpha = G_r + G_m - \min(G_m, H_r).$$

$$H_\alpha = H_r + H_m - \min(G_m, H_r).$$

For a job block having more than two jobs we find the expected flow times by using the fact that the jobs in a job-block are associative. So for three jobs we have, ((i_1, i_2), i_3) = (i_1, (i_2, i_3)).

Step 6: Find the job block β_k that has jobs in an optimal sequence from the given job block β by treating job block β as an associate problem of the given flow shop scheduling problem as explained below:

(A): Find the job J_1 with maximum processing time on first machine and job J_r with least processing time on second machine. If J_1 is not equal to J_r, then we process J_1 at the first place and J_r at the last place and then follow step 6 (C). If $J_1 = J_r$, then we go to step 6 (B).

(B): Find the job J_2 that takes next highest time for processing on first machine. Compute the variation in processing times of jobs J_1 and J_2. Denote this change or difference by A_1. Also locate the job J_{r-1} that takes next minimum time for processing on second machine. Next compute the variation in processing times of jobs J_{r-1} and J_r. Denote this change or difference by A_2. If $A_1 \leq A_2$ then process J_r at the last place and J_2 at the first place otherwise process J_1 on first place and J_{r-1} on the last place. Now go to step 6(C).

(C): Organize the left over (p − 2) jobs in any order among the job J_1 (or J_2) processed at first place and job J_r (or J_{r-1}) processed at last place. Now as a result of structural restrictions we get the job blocks $\beta_1, \beta_2 \ldots \beta_m$ of jobs, where m = (p – 2)!. Each job block has same elapsed time when considered as sub problem of the given shop scheduling problem. Take $\beta_k = \beta_1$ (say).

Step 7: Find the processing times G_{β_k} and H_{β_k} for the job block β_k as explained by Maggu and Das [5] as defined in step 5. Next, replace the given problem by a modified problem by substituting s-jobs by job block α with time taken for processing as G_α and H_α and left over p-jobs by a disjoint job block β_k with processing times G_{β_k} and H_{β_k}.

The modified problem is represented in table-II below:

Table - II: Modified Problem

Jobs	Machine G	Machine H
i	G_i	H_i
α	G_α	H_α
β_k	G_{β_k}	H_{β_k}

Step 8: To find the optimal string S′ we adopt the following method:

(a) Locate the job L_1 which takes maximum processing time on machine G and job L'_1 which takes minimum processing time on machine H. If L_1 is not equal to L'_1, then we process L_1 at the first place and process L'_1 at the last to obtain S′. If $L_1 = L'_1$, then follow step 8(b).

(b) Locate the job L_2 that takes next highest processing time on machine G. Compute the variation in processing times of jobs L_1 and L_2. Denote this change or difference by P'_1. Also locate the job L'_2 that takes next minimum time for processing on machine H. Now compute the variation in processing times of jobs L'_2 and L'_1. Denote this change or difference by P'_2. If P'_1 is less than or equal to P'_2, then we process L'_1 at the last place and L_2 at the first place otherwise we process L_1 first all and L'_2 at the last place to obtain the optimal string S′.

Step 9: Work out the in - out table for sequence σ_k of jobs in string S′ obtained above.

Step 10: Determine the elapsed time T (σ_k), utilization time U_2 (σ_k) and U_3 (σ_k).

VIII. NUMERICAL ILLUSTRATION

Let us process five jobs on three machines in a string of disjoint blocks as job block α = (3, 5) having jobs in fixed order and job block β = (1, 2, 4) with jobs in random order such that $\alpha \cap \beta = \emptyset$. The processing times along with their probabilities are given in table-III:

Table - III: Processing Times for Machines M_1, M_2 & M_3

Jobs	Machine M_1		Machine M_2		Machine M_3	
i	$\tilde{a}_{i1}$	$\tilde{p}_{i1}$	$\tilde{a}_{i2}$	$\tilde{p}_{i2}$	$\tilde{a}_{i3}$	$\tilde{p}_{i3}$
1	16	0.3	12	0.1	13	0.2
2	32	0.1	3	0.3	24	0.1
3	14	0.2	7	0.2	11	0.2
4	26	0.1	9	0.2	7	0.3
5	15	0.3	4	0.2	12	0.2

Solution: Step 1: The expected processing time for machines M_1, M_2 and M_3 are given in table-IV:

Table – IV: Expected Processing Times for Machines M1, M2 and M3

Jobs	Machine M_1	Machine M_2	Machine M_3
i	A_{i1}	A_{i2}	A_{i3}
1	4.8	1.2	2.6
2	3.2	0.9	2.4
3	2.8	1.4	2.2
4	2.6	1.8	2.1
5	4.5	0.8	2.4

Step 2: Condition $\min_i\{A_{i1}\} \geq \max_i\{A_{i2}\}$ or $\min_i\{A_{i3}\} \geq \max_i\{A_{i2}\}$ is satisfied.

Step 3: The processing times G_i and H_i for the fictitious machines G and H are given in the table-V below:

Table - V: Processing Times for machines G & H

Jobs	Machine G	Machine H
i	G_i	H_i
1	6.0	3.8
2	4.1	3.3
3	4.2	3.6
4	4.4	3.9
5	5.3	3.2

Step 4: Check the condition that $\min_i\{G_i\} \geq \max_i\{H_i\}$ or $\max_i\{G_i\} \leq \min_i\{H_i\}$.

Step 5: Find the processing times G_α and H_α for the equivalent job block (3, 5) as:

$G_\alpha = G_r + G_m - \min(G_m, H_r)$ (Here r = 3 & m = 5)
$= 4.2 + 5.3 - \min(5.3, 3.6)$
$= 9.5 - 3.6 = 5.9$

$H_\alpha = H_r + H_m - \min(G_m, H_r)$
$= 3.6 + 3.2 - \min(5.3, 3.6)$
$= 6.8 - 3.6 = 3.2$

Step 6: Since $\min_i\{G_i\} \geq \max_i\{H_i\}$ for job-block β and for this job block max{G_i} = 6.0 for job 1 and min{H_i} = 3.3 for job 2. So by step 6 we get the optimal job-block as β_k = (1, 4, 2).

Step 7: We know that the jobs in a job-block are associative. Thus, for three jobs we have $((i_1, i_2), i_3) = (i_1, (i_2, i_3))$ and so β_k = (1, 4, 2) = ((1, 4), 2) = (α_1, 2), where α_1 = (1, 4).

Therefore,

G_{α_1} = 6.0 + 4.4 – min (4.4, 3.8) = 10.4 − 3.8 = 6.6

H_{α_1} = 3.8 + 3.9 – min (4.4, 3.8) = 7.7 − 3.8 = 3.9

G_{β_k} = 6.6 + 4.1 – min (4.1, 3.9) = 10.7 – 3.9 = 6.8

H_{β_k} = 3.9 + 3.3 – min (4.1, 3.9) = 7.2 – 3.9 = 3.3

The modified problem is defined in table – VI below:

Table - VI: Modified Problem

Jobs	Machine G	Machine H
i	G_i	H_i
α	5.9	3.2
β_k	6.8	3.3

Step 8: Here, Max{G_i} = 6.8 for job block β_k and min{H_i} = 3.2 for job block α. Hence, the optimal string S′ = (β_k, α). In S′ the optimal sequence σ_k of jobs is σ_k = 1 – 4 −2 – 3 – 5. The in-out table for σ_k is:

Table - VII: In-out table for machine order M1 →M2 →M2

Jobs	Machine M_1	Machine M_2	Machine M_3
i	In-Out	In-Out	In-Out
1	0.0 – 4.8	4.8 – 6.0	6.0 – 8.6
4	4.8 – 7.4	7.4 – 9.2	9.2 – 11.3
2	7.4 – 10.6	10.6 – 11.5	11.5 – 13.9
3	10.6 – 13.4	13.4 – 14.8	14.8 – 17.0
5	13.4 – 17.9	17.9 – 18.7	18.7 – 21.1

Thus, total elapsed time T (σ_k) = 21.1 units.

For machine M_2 utilization time U_2 (σ_k) = (18.7 – 4.8) units = 13.9 units.

For machine M_3 utilization time U_3 (σ_k) = (21.1 – 6.0) units = 15.1 units.

IX. DISCUSSION

If we find solution of this problem by using Johnson's [1] technique by treating job block β as associate problem of the given flow shop scheduling problem we obtain β′ = (4, 1, 2) as the optimal job block. The processing time $G_{\beta'}$ and $H_{\beta'}$ for the job block β′ are determined as explained by Maggu and Das [5]. We have, β′ = (4, 1, 2) = ((4, 1), 2) = (α′, 1), where α′ = (4, 1). Therefore,

$G_{\alpha'}$ = 4.4 + 6.0 – min (6.0, 3.9) = 10.4 – 3.9 = 6.5

$H_{\alpha'}$ = 3.9 + 3.8 – min (6.0, 3.9) = 7.7 – 3.9 = 3.8

$G_{\beta'}$ = 6.5 + 4.1 – min (4.1, 3.8) = 10.6 – 3.8 = 6.8

$H_{\beta'}$ = 3.8 + 3.3 – min (4.1, 3.8) = 7.1 – 3.8 = 3.3

The modified problem is defined in table – VIII below:

Table - VIII: Modified Problem for machines G and H

Jobs	Machine G	Machine H
i	G_i	H_i
α	5.9	3.2
β′	6.8	3.3

By Johnson's method [1] we obtain the optimal string S′ = (β′, α). For this optimal string S′, the optimal sequence σ of jobs for the given problem is σ = 4 – 1 – 2 – 3 – 5. The in – out flow table for σ is:

Table - IX: In-out table for machine order M1 →M2 →M2

Jobs	Machine M_1	Machine M_2	Machine M_3
i	In – Out	In - Out	In - Out
4	0.0 − 2.6	2.6 − 4.4	4.4 − 6.5
1	2.6 − 7.4	7.4 − 8.6	8.6 − 11.2
2	7.4 − 10.6	10.6 − 11.5	11.5 − 13.9
3	10.6 − 13.4	13.4 − 14.8	14.8 − 17.0
5	13.4 − 17.9	17.9 − 18.7	18.7 − 21.1

Thus, total elapsed time is T (σ) = 21.1 units.

For machine M_2 utilization time U_2 (σ) = (18.7 − 2.6) units = 16.1 units.

For machine M_3 utilization time U_3 (σ) = (21.1− 4.4) units = 16.7 units.

X. CONCLUSION

The algorithm developed in this paper for specially structured three stage flow shop scheduling problem having probabilities associated to the processing times and with jobs processed in a string of disjoint job blocks achieves better results in comparison to the algorithm given by Johnson [1] for optimization of utilization time of machines. From table - IX we find that the utilization time U_2 (σ) of second machine is 16.1 and utilization time U_3 (σ) of third machine is 16.7 units with make-span of 21.1 units. However, if the proposed algorithm is applied then as per table - VII the utilization time U_2 (σ_k) of second machine is 13.9 units and utilization time U_3 (σ_k) of third machine 15.1 units with the same make-span of 21.1 units. Hence, the algorithm developed in this paper is more resourceful as it optimizes both the elapsed time and utilization time at the same time.

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