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# Heuristic Approach For Weighted Two Stage Flow Shop Model In A String Of Disjoint Job Block Under No Idle Constraint

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**Abstract**—The current paper investigates a two-stage flow shop scheduling model with no idle restriction, in which jobs are scheduled to run in a string of two job blocks that are disjoint in nature, and the jobs processing time is correlated with probabilities. Owing to inherent usefulness as well as relevance in real-world situations, jobs' weight has additionally included. In order to eliminate machine idle time and cutting machine cost of rental, the reason for the conduct of the study is to provide a heuristic algorithm which, once put into practice, processes jobs in optimal way, guarantees in smallest conceivable make span. Multiple computational examples generated in MATLAB 2019a serve as testament to efficacy of the proposed strategy operates. The outcomes are contrasted with the current methods that Johnson and Palmer have demonstrated.

**Keywords**-flow shop; job block; no idle; sequence; scheduling; weightage

## I. INTRODUCTION

The process of scheduling is an essential and integral aspect of resource allocation, wherein the deployment of assets is carefully planned and executed to facilitate the execution of activities. The chief goal of scheduling is in order to identify the most optimal solution, taking into contemplation the pressing desire for optimum a specific purpose or outcome. The well-known flow shop scheduling problem(FSSP) conforms evaluating the best sequence for two or more jobs to be performed on two or more pre-ordered machines to optimize some measure of effectiveness. The critical constraint in an industrialized flow shop scenario is the no-idle time on machines or the inability to halt a machine after it has been started. As a result, there can be no downtime for the machines as they must run continually. Significant emphasis was devoted to resolve the scheduling problem over the past half-century. In the realm of flow shop scheduling problems, Johnson[1]is credited with pioneering the development of a groundbreaking mathematical model. This model, which marked a significant milestone in the field, achieved an optimum solution as a remarkable success. The effectiveness of Johnson's notion grabs considerable interest among multiple scholars, who have a propensity to investigate this tactic. In the realm of research, various researchers, including [2], [3], [4], as well as [5], [6], have made significant contributions by developing upon their initial investigations.

The absence of arguments on the idea of job weightage in scheduling models beforehand 1980 is a notable observation derived from Johnson's pioneering research in 1954. In a two-stage flow shop scheduling method where the processing time is linked to probabilities, including job blocks, they optimized the weighted mean rental cost [7]. A remedy for the 2-machine s, n-jobs flow shop scheduling problem with the intent to further improve the weighted mean flow time of jobs was established [8].

The theory of job block is a relevant and practical approach that aims to strike a balance within the expenditures associated with serving high-priority customers as well as those linked with serving consumers on a regular basis. In domain of flow shop scheduling, the concept of equivalent job per job block was initially proposed [9]in response to the requirement of adhering to specific work orderings due to equipment constraints or third-party policies. To reduce the make-span, Palmer[10]applied the heuristic technique for the problems characterized by a set of n-job m-machine. Taking into account the innate ambiguity in establishing the precise period of job processing, Anup[11]enhanced the investigation to encompass probability within the evaluation of job processing time in an effort to improve the scope of it. Given that work processing times are seldom exact, probabilities are assigned to jobs based on their processing times. The concept of managing jobs within a string that consisted of two distinct job-blocks was investigated in a study [12] .Gupta et al. [13] introduced a flow shop scheduling problem (FSSP) approach. In this approach the jobs are scheduled to run in a string of two job blocks that are disjoint in nature.

No-idle flow shop scheduling entails no-idle constraints, which means that machines constantly operate with no breaks. The first investigation of the m-machine no-idle condition in a flow shop was conducted [14]. While taking job weighting into account, Kaur et al. [15] came up with a way to lower the expense of hiring for the no idle two-stage flow shop scheduling problem. In their study, Singla et al.[16] encountered an innovative methodology for limiting leasing expenses in the context of no idle two-stage flow shop scheduling. By integrating weightage & transit time factors into the scheduling process, the researchers aimed to optimize the allocation of resources and minimize overall rental expenses. The natural world serves as a vast reservoir of knowledge, inspiring organisms to seek solutions to their complex quandaries. Furthermore, scholars and experts have effectively employed this acquired knowledge in order to address intricate engineering dilemmas. The statistical optimization maneuvers in question have been extensively explored and documented in various scholarly works. Notably, researchers have made substantial contributions to the existing literature in this particular domain [17],[18],[19],[20],[21].

Also, authors of this publication are reaching out to a wider audience by including the major jobs in a string of disjoint job blocks, building on the research[15].The current study is centred around the recognition of the finest optimum sequencing of jobs with the objective of lessening expenses associated with the rental of high-cost machinery.

## II. PRACTICAL SITUATION

The presence of various experimental and pratical circumstances is commonly observed throughout everyday involvement in manufacturing and fabrication settings. These scenarios often require the execution of diverse tasks that involve the utilization of different types of industrial equipment. The weightage of jobs can be observed in various industries, including the cotton industry, leather manufacturing unit, and textile factory. These industries serve as practical examples to understand the significance of different job roles and their contributions. Different varieties of cotton, shoes, jackets, and fabric of varying sizes or qualities are carried out in diverse manufacturing facilities, reflecting the diverse range of consumer preferences and market demands. Due to a lack of finances in his early profession, one needs to rent the machines. For example, to start a pathology laboratory, much expensive equipment like a microscope, water bath, lab incubator, glucometer, blood cell counter, organ bath, haematology analyser, urine analyser, centrifuge, coagulometer, autoclave, tissue diagnostics, etc., one does not buy these machines but instead take on rent. Renting enables saving capital investments, helping choose the right equipment for the job and access the latest technology.

## III. NOTATIONS

$i$ : 1, 2,...n sequence of jobs
$s_1$ : Sequence optimization employing Johnson's method
$m_{i1}$ : First machine's i-$^{th}$ job processing time
$m_{i2}$ : Second machine's i-$^{th}$ job processing time
$P_{i1}$ : Probability pertaining to $m_{i1}$
$P_{i2}$ : Probability pertaining to $m_{i2}$
$T_{i2}$ : Second machine's i-$^{th}$ job completion time
$W_i$ : Weightage of i-$^{th}$ job
$u_1(s_1)$ : The time period of machine $M_1$'s utilization within sequence $s_1$
$u_2(s_1)$ : The time period of machine $M_2$'s utilization within sequence $s_1$
$c_1$ : Time-based fees for rental of machine $M_1$
$c_2$ : Time-based fees for rental of machine $M_2$
$l_2$ : To eliminate idle time, the latest time to lease machine $M_2$
$r(s_1)$ : Rental cost for sequence $s_1$

### *A. Assumptions*

- There is no room for any kind of transfer between two different machines, $M_1$ and $M_2$, because of processing of jobs which work autonomously in sequential $M_1M_2$.
- Simultaneous processing of a single job by two machines is not feasible.
- Any alteration to the machines' path of action is strictly prohibited until the completion of said job becomes unattainable.
- Time spent for setting up and equipment break down are not factored into utilization calculations.

### *B. Rental Policy*

The machines are rented on as needed basis and subsequently return them once they are no longer necessary. Specifically, the initial machine acquired through a rental agreement at the commencement of job processing. Subsequently, the second machine will be obtained on a rental basis once the initial job on the first machine has been completed.

## IV. PROBLEM FORMULATION

Consider the processing of jobs i (where i ranges from 1 to n) by two machines, denoted as $M_j$ (where j can take values 1 or 2). Take into account the processing time pertaining to probabilities $P_{ij}$ on the machines $M_j$ denoted by $m_{ij}$. It is assumed that the probabilities $P_{ij}$ satisfy the condition $0 \leq P_{ij} \leq 1$, and the sum of all probabilities for a given job i, denoted by $\Sigma P_{ij}$, equals 1. A string $s_1$ comprising job blocks α and β is expressed as $s_1 = (\boldsymbol{\alpha}, \boldsymbol{\beta})$ where the block $\boldsymbol{\alpha}$ is characterized by a predetermined order of m jobs, selected from a total of n jobs. Conversely, the block $\boldsymbol{\beta}$ comprises r jobs, also chosen from the same set of n jobs, but with no specific order imposed. It is important to note that the sum of m and r must equal the total number of jobs n and $\boldsymbol{\alpha} \cap \boldsymbol{\beta} = \emptyset$, indicating that α and β are mutually exclusive. The model's mathematical representation can be expressed mathematically in the form of TABLE I. in a matrix-based format. In order to minimize capital expenditures for rented equipment, our mission is to pinpoint the optimum jobs {$s_1$} sequence.

TABLE I. MATHEMATICAL FORMULATION IN A MATRIX FORMAT

| **Job** | **Machine $M_1$** | | **Machine $M_2$** | | **Weight** |
|---|---|---|---|---|---|
| ***i*** | $m_{i1}$ | $P_{i1}$ | $m_{i2}$ | $P_{i2}$ | $W_i$ |
| 1 | $m_{11}$ | $P_{11}$ | $m_{12}$ | $P_{12}$ | $W_1$ |
| 2 | $m_{21}$ | $P_{21}$ | $m_{22}$ | $P_{22}$ | $W_2$ |
| 3 | $m_{31}$ | $P_{31}$ | $m_{32}$ | $P_{32}$ | $W_3$ |
| .. | .. | .. | .. | .. | .. |
| n | $m_{n1}$ | $P_{n1}$ | $m_{n2}$ | $P_{n2}$ | $W_n$ |

## V. ALGORITHM

**Step 1:** Determine the anticipated processing times, named as $M_{i1}$& $M_{i2}$, for the machines $M_1$& $M_2$ respectively:

$$M_{i1} = m_{i1} \times P_{i1} \tag{1}$$

$$M_{i2} = m_{i2} \times P_{i2} \tag{2}$$

**Step 2:** For machines $M_1$& $M_2$, use the following equation to determine their respective weighted flow times $M'_{i1}$ and $M'_{i2}$ :

(a) If min ($M_{i1}$ , $M_{i2}$ ) = $M_{i1}$ , then

$$M'_{i1} = \frac{M_{i1}+W_i}{W_i} \tag{3}$$

and

$$M'_{i2} = \frac{M_{i2}}{W_i} \tag{4}$$

**Step 3:** A single job, symbolized by the symbol α, which is defined as (l, m), can be interpreted as the equivalent of the notion of a job block. By implementing the technique proposed, the determination of job α's processing times is scheduled to be conducted [9].

$$\mathrm{M}'_{\alpha 2}=M'_{l2} + M'_{m2} - \min(M'_{m1}, M'_{l2}) \tag{5}$$

$$\mathrm{M}'_{\alpha 2} = M'_{l2} + M'_{m2} - \min(M'_{m1}, M'_{l2}) \tag{6}$$

In the case where three or more jobs comprises job block, the predicted flow timings can be determined by leveraging the property of associativity in the context of equivalent jobs for the job block. Specifically, we can observe that (($j_1$, $j_2$), $j_3$) is equivalent to ($j_1$, ($j_2$, $j_3$))

**Step 4:** Let us contemplate an alternative job block, denoted as β, which possesses a route that is arbitrary in nature, The Johnson's approach[1] is utilized to derive the optimal sequence of jobs within block β (disjoint from job block α). Consider γ represents denote the newly introduced job block. Next, as determined in step 3, determine the block 's processing time.

**Step 5**: In order to reframe the provided problem, into a novel formulation, it is necessary to modify s-jobs by job block α and remaining r = (n − m) jobs can be replaced with a disjoint job block $\gamma$.

**Step 6**: While cutting down on the total amount of time elapsed, implement on Johnson's method[1]to acquire the optimum string $s_1$.

**Step 7**: For computing the total elapsed time for string $s_1$, build a flow in-out table.

**Step 8:** Determine

$$l_2 = T_{i2} - \sum_{n=1}^{\infty} M_{i2} \tag{7}$$

**Step 9:** In order for machine $M_2$ to commence processing, the most recent time $l_2$ considered as the starting point for processing will be employed to generate a flow in-flow out table.

**Step 10:** Calculate utilization time $u_1(s_1)$ and $u_2(s_1)$ of machines $M_1$& $M_2$ by:

$$u_1(s_1) = \sum_{n=1}^{\infty} M_{i1} \tag{8}$$

$$u_2(s_1) = T_{i2} - l_2 \tag{9}$$

**Step 11:** Finally, calculate

$$r(s_1) = u_1(s_1) \times c_1 + u_2(s_1) \times c_2 \tag{10}$$

## VI. NUMERICAL ILLUSTRATION

Taking into consideration, a string $s_1$ where processing durations corresponding to the job weightage and probability are specified in TABLE II. , assume five jobs and two machines. Four and six units of time are needed to hire machines $M_1$ and $M_2$, respectively. By assuming that block $\alpha$ = (5 ,3) has a predetermined order and block $\beta$ = (1 ,2 ,4) able to be positioned in whichever order the machines can be leased for , we aim to attain the best possible job sequencing at the most economical cost.

TABLE II. PROBLEM-SPECIFIC DATA SET

| **Jobs** | **Machine $M_1$** | | **Machine $M_2$** | | **Weight** |
|---|---|---|---|---|---|
| ***i*** | $m_{i1}$ | $P_{i1}$ | $m_{i2}$ | $P_{i2}$ | $W_i$ |
| 1 | 12 | 0.2 | 29 | 0.2 | 5 |
| 2 | 29 | 0.2 | 31 | 0.1 | 6 |
| 3 | 30 | 0.3 | 27 | 0.2 | 7 |
| 4 | 9 | 0.2 | 5 | 0.3 | 8 |
| 5 | 12 | 0.1 | 7 | 0.2 | 4 |

**Solution** : In accordance with Step 1, TABLE III. presents an overview of the anticipated processing times on machines $M_1$ and $M_2$.

TABLE III. EXPECTED PROCESS TIME ON MACHINES

| i | $M_{i1}$ | $M_{i2}$ | $W_i$ |
|---|---|---|---|
| 1 | 2.4 | 5.8 | 5 |
| 2 | 3.0 | 3.1 | 6 |
| 3 | 9.0 | 5.4 | 7 |
| 4 | 1.8 | 1.5 | 8 |
| 5 | 1.2 | 1.4 | 4 |

Following Step 2, TABLE IV. displays weighted flow shop times $M'_{i1}$ and $M'_{i2}$ .

TABLE IV. WEIGHTED FLOW SHOP TIMES

| i | $M'_{i1}$ | $M'_{i2}$ |
|---|---|---|
| 1 | 1.48 | 1.16 |
| 2 | 0.96 | 1.52 |
| 3 | 1.28 | 1.77 |
| 4 | 0.22 | 1.19 |
| 5 | 1.3 | 0.35 |

Select job block $\alpha = (5, 3)$ and $\gamma = (1, 2, 4)$, then computing expected process times as per step 3 are shown in TABLE V. According to step 6 of the research procedure, the sequence $s_1 = \{\gamma, \alpha\}$, where the elements of this sequence are {1, 2, 4, 5, 3} is the optimal one that results in the least amount of time elapsed.

TABLE V. JOB-EQUIVALENT FOR PORTABLE PROCESS TIMES

| i | $M'_{i1}$ | $M'_{i2}$ |
|---|---|---|
| $\alpha$ | 2.23 | 1.77 |
| $\gamma$ | 0.22 | 1.43 |

As presented below, TABLE VI. represents the inflow and outflow based on **Step 7,** for schedule $s_1$ in order to provide a comprehensive overview.

TABLE VI. TABLE FOR FLOW IN AND OUT OF STRING $S_1$

| i | $M_1$ | $M_2$ |
|---|---|---|
| **1** | 0.0 – 2.4 | 2.4 – 8.2 |
| **2** | 2.4 – 5.4 | 8.2 – 11.3 |
| **4** | 5.4 – 7.2 | 11.3 – 12.8 |
| **5** | 7.2 – 8.4 | 12.8 – 14.2 |
| **3** | 8.4 – 17.4 | 17.4 – 22.8 |

Thus, total elapsed time $C_{max} = 22.8$

As per **Step-8;** $l_2 = 22.8 – 17.2 = 5.6$

According to **Step 9** of the research methodology, an IN-OUT table should be created to address the revised scheduling problem, as outlined in TABLE VII.

TABLE VII. TABLE OF FLOW IN-OUT FOR ROUTE $M_1 \rightarrow M_2$ WITH ZERO IDLE TIME

| Jobs | Machine $M_1$ | Machine $M_2$ |
|---|---|---|
| | *Inflow- Outflow* | *Inflow- Outflow* |
| **1** | 0.0 – 2.4 | 5.6 – 11.4 |
| **2** | 2.4 – 5.4 | 11.4 – 14.5 |
| **4** | 5.4 – 7.2 | 14.5 – 16.0 |
| **5** | 7.2 – 8.4 | 16.0 – 17.4 |
| **3** | 8.4 – 17.4 | 17.4 – 22.8 |

As per **Step-10;** $u_1(s_1) = 17.4$
$u_2(s_1) = 22.8 - 5.6 = 17.2$

As per **Step-11;** $r(s_1) = u_1(s_1) * c_1 + u_2(s_1) * c_2$
$= 17.4 * 4 + 17.2 * 6$
$= 172.8$ units

For machine route $M_1 \rightarrow M_2$ of the optimum sequence $s_1 = \{1, 2, 4, 5, 3\}$, the aforementioned computed findings are thus documented in TABLE VIII. Accordingly, the heuristic algorithm proposed for machine route $M_1 \rightarrow M_2$ yields the lowest possible rental cost and utilization time for the optimal solution $s_1$, as shown in TABLE VIII.

TABLE VIII. EVALUATION OF RESULTS IN COMPARISON

| Machine Path $M_1 \rightarrow M_2$ | Rental Costs | Utilization Time of $M_2$ |
|---|---|---|
| ***Proposed Algorithm*** | 172.8 units | 17.2 units |
| ***Johnson Algorithm*** | 192.0 units | 20.4 units |

## VII. COMPUTATIONAL ANALYSIS & RESULTS

In order to analyse the suggested heuristic approach, an arbitrary number of samples for multiple groups each of which has various number of jobs are taken. A total of eight groups, each consisting of job sizes 4, 5, 7, 10, 30, 50, 60, and 80 are created. Each group was then subjected to observation under five distinct tribulations, which were randomly generated. A comparison is made between the overall rental cost in the proposed algorithm and the current make-span techniques of Palmer[10] and Johnson[1]. The results are presented in TABLE IX. and graph was plotted, as shown in Figure 1. , to illustrate the comparison. The findings indicate that, when compared to the remaining curves, the curve associated with the suggested approach has a lower trajectory. Notably, Palmer's algorithm demonstrates a significantly elevated curve compared to other existing approaches.

TABLE IX. COMPUTATIONAL EXPERIMENTS FOR TOTAL RENTAL COST OF MACHINES

| Job Size (n) | Johnson | Palmer | Proposed Algorithm |
|---|---|---|---|
| ***4*** | 168.0 | 168.0 | 158.7 |
| ***5*** | 192.8 | 192.8 | 172.8 |
| ***7*** | 177.7 | 177.9 | 162.5 |
| ***10*** | 223.55 | 225.91 | 213.23 |
| ***30*** | 348.35 | 353.33 | 320.45 |
| ***50*** | 991.85 | 1010.68 | 902.27 |
| ***60*** | 3831.10 | 3915.6 | 3576.6 |
| ***80*** | 15061.68 | 15345.05 | 14031.81 |

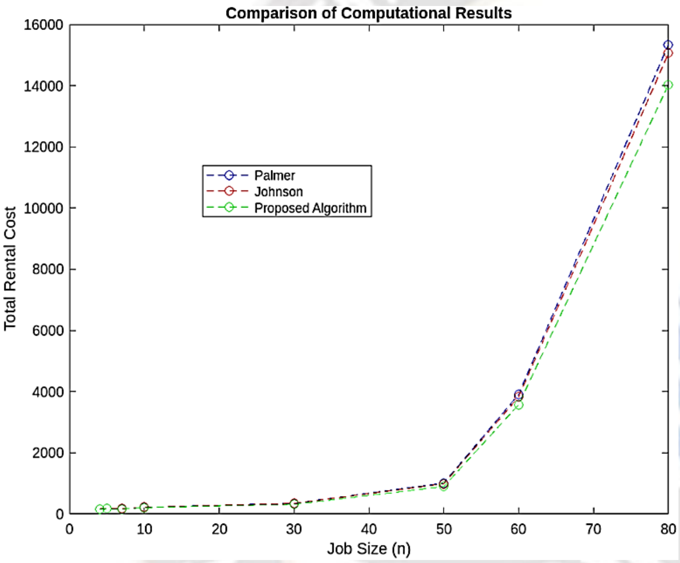

Figure 1. Comparison of Computational Results

Moreover, to assess the quality of the suggested algorithm, calculation of error percentage for each problem follows a specific formula, denoted as $E_{rr}$. This formula is expressed as:

$$[(R_\delta - R_\theta)/ R_\theta] \times 100$$

In this case, $R_\delta$ represents the overall rental cost of all currently available algorithms, while $R_\theta$ represents overall rental cost associated with same job determined when utilizing the new algorithm and results are plotted in the graph below, which is depicted in Figure 2.

TABLE X. AVERAGE ERROR PERCENTAGE

| n | Percentage Error Mean of Total Rental Cost in Palmer algorithm | Percentage Error Mean of Total Rental Cost in Johnson algorithm |
|---|---|---|
| ***4*** | 5.86 | 5.86 |
| ***5*** | 11.57 | 11.57 |
| ***7*** | 9.47 | 9.35 |
| ***10*** | 5.95 | 4.84 |
| ***30*** | 10.26 | 8.71 |
| ***50*** | 12.01 | 9.93 |
| ***60*** | 9.48 | 7.11 |
| ***80*** | 9.36 | 7.34 |

TABLE XI. PERCENTAGE ERROR MEAN ON AVERAGE

| Algorithm | PERCENTAGE ERROR MEAN ON AVERAGE |
|---|---|
| ***Palmer*** | 9.245 |
| ***Johnson*** | 8.09 |

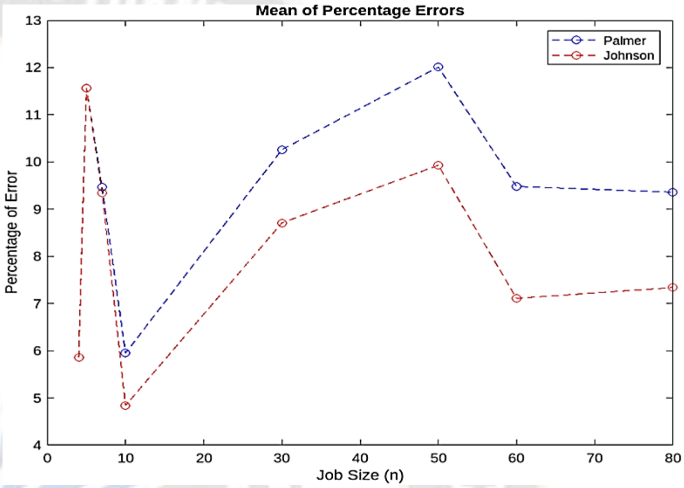

Figure 2. Percentage Error Mean On Average

## VIII. CONCLUSION

In this paper, the proposed heuristic algorithm is provided an optimal result to no-idle two stage flow shop scheduling problem while simultaneously optimizing the rental cost. The algorithm takes into account multiple aspects, including processing time, job weightage and string of disjoint job-blocks. In the present investigation, our primary objective was to attain the desired outcome across various job sizes. Earlier the researchers encompassed small-sized jobs, where the range of n was limited to (1≤n≤8) due to the complexity of computation. But we extended our efforts to encompass medium-sized jobs, with n falling within the range of 9≤n≤30. Furthermore, we sought to accomplish our goal for large-sized jobs, where the value of n ranged from 31 to 80.

In this study, computational testing was conducted to evaluate the performance of a newly developed heuristic algorithm in minimizing rental costs. The results of these experiments indicate that the developed heuristic algorithm surpasses the previously presented heuristics proposed by Palmer[10] and Johnson[1]. Furthermore, this work may also be expanded by taking into account numerous aspects such as job blocking breakdown effect, transportation time etc. More time can be spent on the research by using trapezoidal fuzzy numbers to represent machine processing time.

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