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

Pradeep Bishnoi, Deepak Gupta, Shashi Bala

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. 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].

Cambl 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:

\( \sigma \): Sequence of jobs acquired by using Johnson’s method.

\( \sigma_k \): Sequence of jobs acquired by using the algorithm developed in this paper.

\( M_i \): Machine j.

\( \bar{a}_{ij} \): Time taken for processing the job i on machine j.

\( \bar{p}_{ij} \): Probability attached to \( \bar{a}_{ij} \).

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

\( t_i (\sigma_i) \): Completion time of job i of sequence \( \sigma_i \) on machine j.

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

\( U_i (\sigma_i) \): Utilization time for which machine \( M_i \) is required for sequence \( \sigma_k \).

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

\( \alpha \): Job block having fix order of jobs.

\( \beta \): Job block having random order of jobs.

\( \beta_k \): Job block having jobs in an optimal order acquired by using the algorithm developed in this paper.

\( S \): String of job blocks \( \alpha \) and \( \beta \) i.e. \( S = (\alpha, \beta) \)

\( S' \): Optimal string of job blocks \( \alpha \) and \( \beta_k \).

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 \( M_1 \rightarrow M_2 \rightarrow M_3 \).

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 \((i_1, i_2, \ldots, i_k)\) the job \( i_1 \) has priority 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 \( \min_i \{ A_{i1} \} \geq \max_i \{ A_{i3} \} \)

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 \( \sigma_k \) is respectively defined as:

\[ U_2 (\sigma_k) = T (\sigma_k) - A_{11} (\sigma_k) \]

\[ U_3 (\sigma_k) = T (\sigma_k) - A_{11} (\sigma_k) - A_{12} (\sigma_k) \]

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

| Table – I: Model Formulation |
|-----------------------------|
| **Jobs** | **Machine M1** | **Machine M2** | **Machine M3** |
| i | \( \bar{a}_{i1} \) | \( \bar{p}_{i1} \) | \( \bar{a}_{i2} \) | \( \bar{p}_{i2} \) | \( \bar{a}_{i3} \) | \( \bar{p}_{i3} \) |
| 1 | \( \bar{a}_{11} \) | \( \bar{p}_{11} \) | \( \bar{a}_{12} \) | \( \bar{p}_{12} \) | \( \bar{a}_{13} \) | \( \bar{p}_{13} \) |
| 2 | \( \bar{a}_{21} \) | \( \bar{p}_{21} \) | \( \bar{a}_{22} \) | \( \bar{p}_{22} \) | \( \bar{a}_{23} \) | \( \bar{p}_{23} \) |
| 3 | \( \bar{a}_{31} \) | \( \bar{p}_{31} \) | \( \bar{a}_{32} \) | \( \bar{p}_{32} \) | \( \bar{a}_{33} \) | \( \bar{p}_{33} \) |
| n | \( \bar{a}_{n1} \) | \( \bar{p}_{n1} \) | \( \bar{a}_{n2} \) | \( \bar{p}_{n2} \) | \( \bar{a}_{n3} \) | \( \bar{p}_{n3} \) |

Our objective is to find an optimal job block \( \beta_k \) and hence to find the string \( S' \) having job blocks \( \alpha \) and \( \beta_k \) in an optimal order. Thus, we need to find a sequence \( \sigma_k \) 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 \( T (\sigma_k) \), \( U_2 (\sigma_k) \) and \( U_3 (\sigma_k) \), where \( S = (\alpha, \beta) \).

VII. HEURISTIC ALGORITHM

Step 1: Compute the expected times of processing \( A_{ij} = \bar{a}_{ij} \times \bar{p}_{ij} \).

Step 2: Make sure that the requirements \( \min_i \{ A_{i1} \} \geq \max_i \{ A_{i2} \} \) or \( \min_i \{ A_{i1} \} \geq \max_i \{ A_{i3} \} \) 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:

\[ G_i = A_{i1} + A_{i2} \]

\[ H_i = A_{i2} + A_{i3} \]

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 \( \alpha \) corresponding to the job block say, \( (r, m) \) compute the time \( G_i \) and \( H_i \) taken for processing of this job \( \alpha \) as given by Maggu and Das [5]:

\[ G_i = G_i + G_{in} - \min_i (G_{in}, H_i) \]

\[ H_i = H_i + H_{in} - \min_i (H_{in}, G_i) \]

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 \( \beta_k \) that has jobs in an optimal sequence from the given job block \( \beta \) by treating job block \( \beta \) 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 \( J_1 \) with least processing time on second machine. If \( J_1 \) is not equal to \( J_n \), then we process \( J_1 \) at the first place and \( J_n \) at the last place and then follow step 6 (C). If \( J_1 \) = \( J_n \) then we go to step 6 (B).
(B): Find the job J₂ that takes next highest time for processing on first machine. Compute the variation in processing times of jobs J₁ and J₂. Denote this change or difference by A₁. Also locate the job Jᵢ₊₁ that takes next minimum time for processing on second machine. Next compute the variation in processing times of jobs Jᵢ₊₁ and Jᵢ. Denote this change or difference by A₂. If A₁ ≤ A₂ then process Jᵢ at the last place and J₂ at the first place otherwise process J₁ on first place and Jᵢ₊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 J₁ (or J₂) processed at first place and job Jᵢ (or Jᵢ₊₁) processed at last place. Now as a result of structural restrictions we get the job blocks β₁, β₂ ... βₘ of jobs, where m = (p – 2)/2. Each job block has same elapsed time when considered as sub problem of the given shop scheduling problem. Take βᵢ = β₁ (say).

Step 7: Find the processing times Gᵦᵢ and Hᵦᵢ for the job block βᵢ 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 Gᵦ and Hᵦ and left over p-jobs by a disjoint job block βᵢ with processing times Gᵦᵢ and Hᵦᵢ. The modified problem is represented in table-II below:

| Table - II: Modified Problem |
|------------------------------|
| Jobs | Machine G | Machine H |
| i    | Gᵦᵢ        | Hᵦᵢ        |
| α    | Gᵦ          | Hᵦ          |
| βᵢ   | Gᵦᵢᵢ       | Hᵦᵢᵢ       |

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

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

(b) Locate the job L₂ that takes next highest processing time on machine G. Compute the variation in processing times of jobs L₁ and L₂. Denote this change or difference by P₁. Also locate the job L₂’ that takes next minimum time for processing on machine H. Now compute the variation in processing times of jobs L₂’ and L₂. Denote this change or difference by P₂. If P₁ is less than or equal to P₂, then we process L₂’ at the last place and L₂ at the first place otherwise we process L₁ first and L₂ at the last place to obtain the optimal string S’.

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

Step 10: Determine the elapsed time T (σₐ), utilization time U₂ (σₐ) and U₃ (σₐ).

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 α ∩ β = Ø. The processing times along with their probabilities are given in table-III:

| Table - III: Processing Times for Machines M₁, M₂, & M₃ |
|---------------------------------------------------------|
| Jobs | Machine M₁ | Machine M₂ | Machine M₃ |
| i    | aᵢ₁        | Pᵢ₁        | aᵢ₂        | Pᵢ₂        | aᵢ₃        | Pᵢ₃        |
| 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 M₁, M₂ and M₃ are given in table-IV:

| Table - IV: Expected Processing Times for Machines M₁, M₂ and M₃ |
|---------------------------------------------------------------|
| Jobs | Machine M₁ | Machine M₂ | Machine M₃ |
| i    | Aᵢ₁        | Aᵢ₂        | Aᵢ₃        |
| 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 minᵢ{Aᵢ₁} ≥ maxᵢ{Aᵢ₂} or minᵢ{Aᵢ₃} ≥ maxᵢ{Aᵢ₂} is satisfied.

Step 3: The processing times Gᵦ and Hᵦ 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    | Gᵦᵢ        | Hᵦᵢ        |
| 1    | Gᵦ₁        | Hᵦ₁        |
| 2    | 6.0        | 3.8        |
| 3    | 4.1        | 3.3        |
| 4    | 4.2        | 3.6        |
| 5    | 4.4        | 3.9        |

Step 4: Check the condition that minᵢ{Gᵦᵢ} ≥ maxᵢ{Hᵦᵢ} or maxᵢ{Gᵦᵢ} ≤ minᵢ{Hᵦᵢ}.

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

Gᵦᵢ = Gᵦ₁ + Gᵦ₃ − minᵢ{Gᵦᵢ₁, Hᵦ₁} (Here r = 3 & m = 5)

= 4.2 + 5.3 − min (5.3, 3.6)

= 5.9 − 3.6 = 2.3

Hᵦᵢ = Hᵦ₁ + Hᵦ₃ − minᵢ{Gᵦᵢ₁, Hᵦ₁}

= 3.6 + 3.2 − min (5.3, 3.6)

= 6.8 − 3.6 = 3.2

Step 6: Since minᵢ{Gᵦᵢ} ≥ maxᵢ{Hᵦᵢ} for job-block β and for this job block maxᵢ{Gᵦᵢ} = 6.0 for job 1 and minᵢ{Hᵦᵢ} = 3.3 for job 2. So by step 6 we get the optimal job-block as β₈ = (1, 4, 2).

Step 7: We know that the jobs in a job-block are associative. Thus, for three jobs we have ((i₁, i₂), i₃) = (i₁, (i₂, i₃)) and so β₈ = (1, 4, 2) = ((1, 4), 2) = (a₁, 2), where a₁ = (1, 4).

Therefore,

Gᵦ₁ = 6.0 + 4.4 − min (4.4, 3.8) = 10.4 − 3.8 = 6.6

Hᵦ₁ = 3.8 + 3.9 − min (4.4, 3.8) = 7.7 − 3.8 = 3.9

Gᵦ₈ = 6.6 + 4.1 − min (4.1, 3.9) = 10.7 − 3.9 = 6.8

Hᵦ₈ = 3.9 + 3.3 − min (4.1, 3.9) = 7.2 − 3.9 = 3.3
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The modified problem is defined in Table – VI below:

| 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:

| 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^*_β and H^*_β 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^*_β = 4.4 + 6.0 - min (6.0, 3.9) = 10.4 - 3.9 = 6.5

H^*_β = 3.9 + 3.8 - min (6.0, 3.9) = 7.7 - 3.9 = 3.8

G^*_β = 6.5 + 4.1 - min (4.1, 3.8) = 10.6 - 3.8 = 6.8

H^*_β = 3.8 + 3.3 - min (4.1, 3.8) = 7.1 - 3.8 = 3.3

The modified problem is defined in Table – VIII below:

| 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:

| 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.

REFERENCES

1. S. M. Johnson, “Optimal two and three stage production schedule with setup time included”, Nav. Res. Log. Quarterly, vol. 1 (1), 1954, pp. 61-68.
2. R. D. Smith and R. A. Dudek, “A general algorithm for solution of the n-jobs, m-machines sequencing problem of the flow-shop”, Operations Research, vol. 15(1), 1967, pp. 71-82.
3. H. A. Cambell, R. A. Dudek and M. L. Smith, “A heuristic algorithm for n-jobs, m-machines sequencing problem”, Management Science, vol. 16, 1970, pp. 630-637.
4. J. N. D. Gupta, “Optimal Schedule for specially structured flow shop”, Naval Research Logistic, vol. 22 (2), 1975, pp. 255-269.
5. P. L. Maggu and G. Das, “Equivalent jobs for job block in job sequencing”, Opsearch, vol. 5, 1977, pp. 293-298.
6. A. P. D. Heydari, “On flow shop scheduling problem with processing of jobs in string of disjoint job blocks: fixed order jobs and arbitrary order jobs,” JISSOR, vol. XXIV (1-4), 2003, pp. 39-43.
7. T. P. Singh, R. Kumar and D. Gupta, “Optimal three stage production schedule, the processing time and set up times associated with probabilities including job block criteria”, published in Proceedings of National Conference on FACM, 2005, pp. 463-470.
8. D. Gupta, S. Sharma and N. Gulati, “n × 3 flow shop production schedule, processing time, set up time, each associated with probabilities along with jobs in a string of disjoint job block”, Antarcitca Journal of Mathematics, vol. 8(5), 2011, pp. 443-457.
9. D. Gupta, S. Sharma and S. Bala, “Specially Structured Two Stage Flow Shop Scheduling To Minimize the Rental Cost”, International Journal of Emerging trends in Engineering and Development, vol. 1 (2), 2012, pp. 206-215.
10. D. Gupta, S. Sharma and S. Aggarwol, “Three stage constrained flow shop scheduling with jobs in a string of disjoint job block”, Proceeding of IEEE Xplore, International Conference on Engineering and System (SCES), 2012, pp. 392-397.
11. D. Gupta, S. Bala, P. Singla and S. Sharma, “3- Stage Specially Structured Flow Shop Scheduling to minimize the rental cost including transportation time, job weightage and job block criteria”, European Journal of Business and Management, vol. 7(4), 2015, pp. 1-6.
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