

Heuristic for Three Machines in Tandem with Setup and Transportation Times of Jobs

Richa Mehrotra¹, Qazi Shoeb Ahmad²

Assistant Professor, Department of Mathematics, Amity University Uttar Pradesh, Lucknow, India¹

Department of Statistics, Science Unit, Deanship of Educational Services, Qassim University, Buraidah, KSA²

ABSTRACT: In this paper, we have considered the problem of three machines in tandem including the setup times and transportation times for jobs. Also, we have considered break-down time of machines and weights of jobs according to their importance in the sequence. A heuristic approach has been made for finding an optimal schedule. The procedure has been illustrated with the help of a numerical example.

KEYWORDS: Machines in tandem, setup time, transportation time, break-down time, weight of jobs.

I. INTRODUCTION

Jackson [10] gave the idea of two production stages while studying a queuing system concerned with an industry in which the production of an item takes place in two distinct but successive stages. Jackson [10] called such stages in tandem (or in series). Johnson [11] and Bellman [3] studied the problem of scheduling of n jobs on two machines arranged in tandem where time required to transport jobs from first machine to the second was assumed to be negligible. Ignall and Schrage [9] proposed an algorithm to optimize makespan for multi-machine and n jobs. As the problem size increases, NP-completeness of flow shop problems necessitates the development of heuristics to get near optimal solutions. Campbell, Dudek and Smith [4] proposed a heuristic algorithm to minimize the makespan. In their work, they split the given m machine problem into a series of equivalent two machine flowshop problem and solving it using Johnson's method. Another heuristic was proposed by Nawaz, Ensore and Ham [15] for minimizing makespan time.

Apart from the makespan objective, other significant objectives like total flow time, tardiness and middle time of machines have been proposed by different authors. Ho and Chang [8] have attempted not only minimizing makespan but also minimizing total flow time and machine idle time. Chou and Lee [6] attempted to solve two machine flowshop bi-criteria scheduling problem with release dates for the jobs, in which the objective function is to minimize the weighted sum of total flow time and makespan. Allahverdi and Aldowaisan [1] reported in their work about a three machines no-wait flow-shop problem with the objective of minimizing total completion time where setup times are considered as separate from processing times and sequence independent. Rajendran and Ziegler [19] have considered the objective of minimizing the total weighted flow times of jobs. Rajendran and Chaudhuri [18] have proposed a heuristic algorithm to minimize the total flow time by approaching the problem in multistage. Maggu and Das [14] used the concept of transportation time in going from one stage to the other. They studied a system in which an infinite number of transport agents were available and no transport agent was required to return to stage 1 from stage 2. It was assumed that Machine-1 starts processing the next item immediately after finishing the preceding one. Here, we have considered the problem of three machines in tandem including the setup times and transportation times for jobs. Further, we have considered break-down time of machines and weights of jobs according to their importance in the sequence.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

II. THREE MACHINES AND N-JOBS FLOW-SHOP SCHEDULING PROBLEM INVOLVING TRANSPORTATION TIME AND SETUP TIME OF JOBS

Let us consider n items (I_1, I_2, \dots, I_n) being processed through three machines $(A, B \text{ and } C)$ in the order ABC with agents who transport an item processed at machine A to the machine B and then to machine C . Let item i to be processed on the three machines $(A, B \text{ and } C)$ requires setup times denoted by a_i, b_i and c_i respectively. Let t_i and g_i be the transportation times for item i to carry it from machine A to B and B to C respectively. The problem is to find an optimal schedule of items to minimize the total production time for completing all the items.

THEOREM1 An optimal sequence is obtained by sequencing the item $i-1, i, i+1$ such that:

$$\min \{a_i + A_i + t_i + b_i + B_i + g_i, t_{i+1} + b_{i+1} + B_{i+1} + g_{i+1} + c_{i+1} + C_{i+1}\} \\ < \min \{a_{i+1} + A_{i+1} + t_{i+1} + b_{i+1} + B_{i+1} + g_{i+1}, t_i + b_i + B_i + g_i + c_i + C_i\}$$

PROOF To prove this theorem, we first prove the following lemma:

LEMMA1 If $\min \{a_i + A_i + t_i\} \geq \max \{b_i + B_i + t_i\}$, then $CA_p + t_p \geq CB_{p-1}$.

PROOF Consider the statement $P(q)$ for an arbitrary number q defined as:

$$P(q): CA_{q+1} + t_{q+1} \geq CB_q \quad (q = 1, 2, \dots)$$

For any arbitrary natural number q

$$CA_1 = a_1 + A_1$$

$$CB_1 = a_1 + A_1 + t_1 + b_1 + B_1$$

$$CA_2 + t_2 = a_1 + A_1 + a_2 + A_2 + t_2$$

Since $\min \{a_i + A_i + t_i\} \geq \max \{b_i + B_i + t_i\}$

$$\Rightarrow CA_2 + t_2 > CB_1.$$

Hence, $P(q)$ be true for $q = 1$.

Let $P(q)$ be true for $q = m$, i.e.

$$CA_{m+1} + t_{m+1} \geq CB_m.$$

Now,

$$CB_{m+1} = \max \{CA_{m+1} + t_{m+1}, CB_m\} + b_{m+1} + B_{m+1}$$

$$= CA_{m+1} + (t_{m+1} + b_{m+1} + B_{m+1})$$

But $CA_{m+2} + t_{m+2} = CA_{m+1} + a_{m+2} + A_{m+2} + t_{m+2}$ and $a_{m+2} + A_{m+2} + t_{m+2} \geq b_{m+1} + B_{m+1} + t_{m+1}$

Hence, $CA_{m+2} + t_{m+2} \geq CB_{m+1}$.

Therefore, $P(q)$ is true for $q = m + 1$.

We now proceed to the proof of the theorem.

Let S and S' denote the sequences of items given by:

$$S = (I_1, I_2, \dots, I_{i-1}, I_i, I_{i+1}, I_{i+2}, \dots, I_n)$$

$$S' = (I'_1, I'_2, \dots, I'_{i-1}, I'_i, I'_{i+1}, I'_{i+2}, \dots, I'_n)$$

Let (X_p, X'_p) and $(CX_p, C'X_p)$ be respectively the processing time and completion time of any item p on machine $X (= A \text{ or } B)$ for the sequences (S, S') . Let (t_p, t'_p) and (g_p, g'_p) denotes the transportation times of item p to transport it from machine A to machine B and from machine B to machine C respectively for the sequences (S, S') . Let (a_p, a'_p) , (b_p, b'_p) and (c_p, c'_p) be respectively the setup times of an item p on machines A, B and C for the sequences (S, S') .

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

The completion time of p^{th} item on machines B and C is given by

$$\begin{aligned} CB_p &= \max \{CA_p + t_p, CB_{p-1}\} + b_p + B_p \\ &= CA_p + t_p + b_p + B_p \\ CC_p &= \max \{CB_p + g_p, CC_{p-1}\} + c_p + C_p \\ &= \max \{CA_p + t_p + b_p + B_p + g_p, CC_{p-1}\} + c_p + C_p \end{aligned} \quad (1)$$

Now, we will choose the sequence S if

$$CC_n < C'C_n \quad (2)$$

i.e., if

$$\max (CA_n + t_n + b_n + B_n + g_n, CC_{n-1}) + c_n + C_n < \max (C'A_n + t'_n + b'_n + B'_n + g'_n, C'C_{n-1}) + c'_n + C'_n$$

Now $CA_n + t_n + b_n + B_n + g_n = C'A_n + t'_n + b'_n + B'_n + g'_n$, $c_n = c'_n$ and $C_n = C'_n$, so the result (2) will be true if:

$$CC_{n-1} < C'C_{n-1} \quad (3)$$

Proceeding in this way we get that inequality (2) is true if:

$$CC_p < C'C_p \quad (p = i+1, i+2, \dots, n \text{ and } i = 1, 2, \dots, n-1) \quad (4)$$

We now calculate the values of CC_{i+1} and $C'C_{i+1}$

$$\begin{aligned} CC_{i+1} &= \max \{CB_{i+1} + g_{i+1}, CC_i\} + c_{i+1} + C_{i+1} \\ &= \max \{CA_{i+1} + t_{i+1} + b_{i+1} + B_{i+1} + g_{i+1}, CC_i\} + c_{i+1} + C_{i+1} \\ CC_{i+1} &= \max \{CA_{i+1} + t_{i+1} + b_{i+1} + B_{i+1} + g_{i+1}, \max \{CB_i + g_i, CC_{i-1}\} + c_i + C_i\} + c_{i+1} + C_{i+1} \\ &= \max \{CA_{i+1} + t_{i+1} + b_{i+1} + B_{i+1} + g_{i+1}, CB_i + g_i + c_i + C_i, CC_{i-1} + c_i + C_i\} + c_{i+1} + C_{i+1} \\ &= \max \{CA_{i+1} + t_{i+1} + b_{i+1} + B_{i+1} + g_{i+1}, \max \{CA_i + t_i, CB_{i-1}\} + b_i + B_i + g_i + c_i + C_i, \\ &\quad CC_{i-1} + c_i + C_i\} + c_{i+1} + C_{i+1} \\ &= \max \{CA_{i+1} + t_{i+1} + b_{i+1} + B_{i+1} + g_{i+1}, CA_i + t_i + b_i + B_i + g_i + c_i + C_i, \\ &\quad CC_{i-1} + c_i + C_i\} + c_{i+1} + C_{i+1} \\ CC_{i+1} &= \max \{CA_{i-1} + a_i + A_i + a_{i+1} + A_{i+1} + t_{i+1} + b_{i+1} + B_{i+1} + g_{i+1} + c_{i+1} + C_{i+1}, \\ &\quad CA_{i-1} + a_i + A_i + t_i + g_i + b_i + B_i + c_i + C_i + c_{i+1} + C_{i+1}, \\ &\quad CC_{i-1} + c_i + C_i + c_{i+1} + C_{i+1}\} \end{aligned} \quad (5)$$

Similarly,

$$\begin{aligned} C'C_{i+1} &= \max \{C'A_{i-1} + a'_i + A'_i + a'_{i+1} + A'_{i+1} + t'_{i+1} + b'_{i+1} + B'_{i+1} + g'_{i+1} + c'_{i+1} + C'_{i+1}, \\ &\quad C'A_{i-1} + a'_i + A'_i + t'_i + g'_i + b'_i + B'_i + c'_i + C'_i + c'_{i+1} + C'_{i+1}, \\ &\quad C'C_{i-1} + c'_i + C'_i + c'_{i+1} + C'_{i+1}\} \end{aligned} \quad (6)$$

Comparing the sequences S and S' , it is obvious that

$$\begin{aligned} CA_{i-1} &= C'A_{i-1}, CC_{i-1} = C'C_{i-1} \\ X_i &= X'_{i+1}, X_{i+1} = X'_i \quad (X = a, b, A, B \text{ or } C) \\ t_i &= t'_{i+1}, t_{i+1} = t'_i, g_i = g'_{i+1}, g_{i+1} = g'_i \end{aligned} \quad (7)$$

Writing (4) for $p = i+1$ and using (7), we get

$$\begin{aligned} &\max \{CA_{i-1} + a_i + A_i + a_{i+1} + A_{i+1} + t_{i+1} + b_{i+1} + B_{i+1} + g_{i+1} + c_{i+1} + C_{i+1}, CA_{i-1} + a_i + A_i + \\ &\quad t_i + g_i + b_i + B_i + c_i + C_i + c_{i+1} + C_{i+1}, CC_{i-1} + c_i + C_i + c_{i+1} + C_{i+1}\} \\ &< \max \{CA_{i-1} + a_{i+1} + A_{i+1} + a_i + A_i + t_i + b_i + B_i + g_i + c_i + C_i, CA_{i-1} + a_{i+1} + A_{i+1} + \\ &\quad t_{i+1} + g_{i+1} + b_{i+1} + B_{i+1} + c_{i+1} + C_{i+1} + c_i + C_i, CC_{i-1} + c_{i+1} + C_{i+1} + c_i + C_i\} \end{aligned} \quad (8)$$

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Subtracting last term from both sides and further subtracting $CA_{i-1} + a_i + A_i + a_{i+1} + A_{i+1} + t_i + t_{i+1} + g_i + g_{i+1} + b_i + B_i + b_{i+1} + B_{i+1} + c_i + C_i + c_{i+1} + C_{i+1}$ from each side, we get

$$\max \{-t_i - g_i - b_i - B_i - c_i - C_i, -a_{i+1} - A_{i+1} - t_{i+1} - g_{i+1} - b_{i+1} - B_{i+1}\} \\ < \max \{-t_{i+1} - g_{i+1} - b_{i+1} - B_{i+1} - c_{i+1} - C_{i+1}, -a_i - A_i - t_i - g_i - b_i - B_i\} \quad (9)$$

$$\min \{a_i + A_i + t_i + g_i + b_i + B_i, t_{i+1} + g_{i+1} + b_{i+1} + B_{i+1} + c_{i+1} + C_{i+1}\} \\ < \min \{a_{i+1} + A_{i+1} + t_{i+1} + g_{i+1} + b_{i+1} + B_{i+1}, t_i + g_i + b_i + B_i + c_i + C_i\} \quad (10)$$

The utility of above theorem can be summarized into following steps to give us decomposition algorithm, that is, numerical method to obtain an optimal schedule minimizing total elapsed time for a 3-machine, n-job sequencing problem where setup and transportation times are taken into account. Our problem can be represented in tableau form as follows:

Item i	a_i	Machine A (A_i)	t_i	b_i	Machine B (B_i)	g_i	c_i	Machine C (C_i)
1	a_1	A_1	t_1	b_1	B_1	g_1	c_1	C_1
2	a_2	A_2	t_2	b_2	B_2	g_2	c_2	C_2
•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•
n	a_n	A_n	t_n	b_n	B_n	g_n	c_n	C_n

Where A_i, B_i, C_i are the service times on A, B and C respectively. a_i, b_i, c_i are the setup times on A, B and C respectively. t_i, g_i are the transportation times of item i from machine A to B and B to C respectively satisfying the structural relationship:

- i) $\min(a_i + A_i + t_i) \geq \max(b_i + B_i + t_i)$
- ii) $\min(c_i + C_i + g_i) \geq \max(b_i + B_i + g_i)$

ALGORITHM1 The result of theorem-1 gives the following procedure for an optimal sequence:

Step1: Assume that there are two fictitious machines G and H in place of A and B respectively. The service times for these fictitious machines are given by G_i and H_i where

$$G_i = a_i + A_i + t_i + b_i + B_i + g_i, \quad H_i = t_i + b_i + B_i + g_i + c_i + C_i$$

Step2: Applying Johnson's (1954) rule to the fictitious machine times G & H constructed in step 1, we obtain the optimal sequence.

III. FLOW-SHOP SCHEDULING ALSO INVOLVING JOB WEIGHTS AND BREAK-DOWN INTERVALS OF MACHINES

Let job i be assigned with the weight w_i according to its relative importance for performance in the given sequence. The performance measure studied is weighted mean flow time defined by:

$$\bar{F}_w = \frac{\sum_{i=1}^n w_i f_i}{\sum_{i=1}^n w_i}, \text{ where } f_i \text{ is the flow time of } i^{th} \text{ job.}$$

Let the break-down interval (a, b) is already known to us, i.e., deterministic nature and the break-down interval length is $(b - a)$, which is known. Then our aim is to find out an optimal sequence of jobs so as to minimize the total elapsed time.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

The given problem can be represented in tableau form as follows:

Item i	a_i	Machine A (A_i)	t_i	b_i	Machine B (B_i)	g_i	c_i	Machine C (C_i)	w_i
1	a_1	A_1	t_1	b_1	B_1	g_1	c_1	C_1	w_1
2	a_2	A_2	t_2	b_2	B_2	g_2	c_2	C_2	w_2
•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•
n	a_n	A_n	t_n	b_n	B_n	g_n	c_n	C_n	w_n

ALGORITHM2 The steps are as follows:

Step1: Modify the problem into two machines flow-shop problem using fictitious machines (G and H) as in algorithm-

1. The modified problem in the tabular form is:

Item i	Machine G $G_i = a_i + A_i + t_i + b_i + B_i + g_i$	Machine H $H_i = t_i + b_i + B_i + g_i + c_i + C_i$	Weight w_i
1	G_1	H_1	w_1
2	G_2	H_2	w_2
•	•	•	•
•	•	•	•
n	G_n	H_n	w_n

Step2: Find $\min(G_i, H_i)$

i) If $\min(G_i, H_i) = G_i$ then define $G'_i = G_i - w_i$ and $H'_i = H_i$.

ii) If $\min(G_i, H_i) = H_i$ then define $G'_i = G_i$ and $H'_i = H_i + w_i$.

Step3: Define a new reduced problem in the tabular form as:

Item i	G'_i	H'_i
1	G'_1 / w_1	H'_1 / w_1
2	G'_2 / w_2	H'_2 / w_2
•	•	•
•	•	•
n	G'_n / w_n	H'_n / w_n

Step4: Determine the optimal sequence by using Johnson's algorithm for the new reduced problem obtained in step3 and see the effect of break-down interval (a, b) on different jobs.

Step5: Formulate a new problem with processing time A'_i , B'_i and C'_i where

$A'_i = A_i + (b - a)$, $B'_i = B_i + (b - a)$ and $C'_i = C_i + (b - a)$, if (a, b) has an effect on job i .

$A'_i = A_i$, $B'_i = B_i$, $C'_i = C_i$, if (a, b) has no effect on job i .

Step6: Now repeat the procedure to get the optimal sequence.

This sequence is an optimal for the original problem. By this sequence, we can determine the total elapsed time and weighted mean-flow time.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

EXAMPLE Let a machine tandem queuing problem be given in the following tableau form:

Item i	a_i	Machine A (A_i)	t_i	b_i	Machine B (B_i)	g_i	c_i	Machine C (C_i)	w_i
1	2	4	6	2	3	2	3	5	3
2	3	6	4	1	4	6	4	7	5
3	2	4	7	2	3	2	3	8	4
4	4	9	3	3	6	8	2	10	2

SOLUTION Now $\min(a_i + A_i + t_i) = 12$

$$\max(b_i + B_i + t_i) = 12$$

Hence, Structural condition (i) is satisfied. Now, using the step 1, the reduced problem is:

Item i	Machine G $G_i = a_i + A_i + t_i + b_i + B_i + g_i$	Machine H $H_i = t_i + b_i + B_i + g_i + c_i + C_i$	Weight w_i
1	19	21	3
2	34	26	5
3	20	25	4
4	33	32	2

Using steps 2 to 4 and applying Johnson's rule, the optimal sequence is (3, 1, 4, 2). Now the effects of break-down interval (18, 25) on sequence (3,1,4,2) is read as follows:

Item i	a_i	A In-out	t_i	b_i	B In-out	g_i	c_i	C In-out	w_i
3	2	2-6	7	2	15-18	2	3	23-31	4
1	2	8-12	6	2	20-23	2	3	34-39	3
4	4	16-25	3	3	31-37	8	2	47-57	2
2	3	28-34	4	1	39-43	6	4	61-68	5

Hence, with effect of break-down interval the original problem gets modified to a new problem (as per step 5).

Item i	a_i	Machine A (A'_i)	t_i	b_i	Machine B (B'_i)	g_i	c_i	Machine C (C'_i)	w_i
1	2	4	6	2	10	2	3	5	3
2	3	6	4	1	4	6	4	7	5
3	2	4	7	2	3	2	3	15	4
4	4	16	3	3	6	8	2	10	2

Now, repeating the procedure, we get the sequence (2,3,1,4) which is optimal or near optimal and the final table is:

Item i	a_i	A In-out	t_i	b_i	B In-out	g_i	c_i	C In-out	w_i
2	3	3-9	4	1	14-18	6	4	28-35	5
3	2	11-15	7	2	24-27	2	3	38-53	4
1	2	17-21	6	2	29-39	2	3	56-61	3
4	4	25-41	3	3	47-53	8	2	63-73	2

Mean weighted flow time is =
$$\frac{35 \times 5 + (53 - 9) \times 4 + (61 - 15) \times 3 + (73 - 21) \times 2}{5 + 4 + 3 + 2}$$

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

= 42.36 hrs.

Hence, the total elapsed time is 73 hrs. and mean weighted flow time is 42.36 hrs.

IV. CONCLUSIONS

The paper dealt with an important problem in scheduling theory with the objectives to minimize the makespan and the mean weighted flow time for three machines in tandem including the setup times and transportation times for jobs. The concept of setup time is very important in some cases as in dyeing industries, automobile industries etc. Also, we have considered break-down time of machines and weights of jobs according to their importance in the sequence, this case can also help in considering lunch times for workers or servicing needed for machines. A heuristic approach has been made for finding an optimal schedule. This approach is fast to achieve the objectives.

REFERENCES

- [1] A. Allahverdi and T. Aldowaisa, "No-wait and separate setup three machine flow shop with total completion time criterion", International Transactions in Operations Research, Vol. 7, pp. 245–264, 2000.
- [2] R. C. Aziz and T. P. Singh, "On Heuristic principle of Dominance for solution of Scheduling with transportation time for a job given", Journal of Indian Society of Statistics and Operations Research, Vol. 7, pp. 15-19, 1991.
- [3] R. Bellman, "Mathematical aspects of scheduling theory", J. Soc. Indus. Appl. Math., Vol. 4, pp. 168-205, 1956.
- [4] H. G. Campbell, R. A. Dudek and M. L. Smith, "A heuristic algorithm for the n-job m-machine sequencing problem", Manage Science, Vol. 16, No. 16, pp. 630–637, 1970.
- [5] A. B. Chandramouli, "Heuristic approach for n-job, 3-machine flow-shop scheduling problem involving transportation time, break-down time and weights of jobs", Mathematical and Computational Applications, Vol. 10, No. 2, pp. 301-305, 2005.
- [6] F-D Chou and C-E Lee, "Two-machine flowshop scheduling with bicriteria problem", Comput Ind Eng, Vol. 36, pp. 549–564, 1999.
- [7] J.N.D. Gupta and Jr. E.F. Stafford, "Flowshop scheduling research after five decades", European Journal of Operational Research, Vol. 169, No. 3, pp. 699-711, 2006.
- [8] J.C. Ho and Y.L. Chang, "A new heuristic for the n-jobs, m-machine flowshop scheduling", Math Oper Res, Vol. 1, pp. 117–129, 1976.
- [9] E. Ignall and L. Schrage, "Application of the branch and bound technique to some flow shop scheduling problems", Oper Res, Vol. 13, pp. 400–412, 1965.
- [10] R.R.P. Jackson, "Queuing systems with phase-type service", O.R. Quart., Vol. 5, pp. 109-120, 1954.
- [11] S.M. Johnson, "Optimal two-and-three stage production scheduling", Naval. Rs. Log. Quart., Vol. 1, pp. 61-68, 1954.
- [12] S.U. Khan, P.L. Maggu and M.H. Mudawi, "Two machines in tandem with a single transport agent in between-A heuristic approach", PAMS, Vol. 40, pp. 11-21, 1994.
- [13] A. Khodadadi, "Development of a new heuristic for three machine flow-shop scheduling problem with transportation time of job", WASJ, Vol. 5, No. 5, pp. 598-601, 2008.
- [14] P. L. Maggu and G. Das, "On $2 \times n$ sequencing problem with transportation times of jobs", PAMS, Vol. 12, No. 1-2, pp. 1-6, 1980.
- [15] M. Nawaz, E. Emory and I. Ham, "A heuristic algorithm for the m-machine, n-jobs flow shop sequencing problem", Omega, Vol. 11, pp. 91–95, 1983.
- [16] C. N. Potts and M. Y. Kovalyov, "Scheduling with batching: a review", European Journal of Operational Research, Vol. 120, pp. 228-249, 2000.
- [17] C. Proust, J. N. D. Gupta and V. Deschamps, "Flowshop scheduling with set-up, processing and removal times separated", Int. J. Prod. Res. Vol. 29, pp. 479-493, 1991.
- [18] C. Rajendran and D. Chaudhuri, "An efficient heuristic approach to the scheduling of jobs in a flow shop", European Journal of Operational Research, Vol. 61, pp. 318–325, 1992.
- [19] C. Rajendran and H. Ziegler, "An efficient heuristic for scheduling in flow shop to minimize total weighted flow time of jobs", European Journal of Operational Research, Vol. 103, pp. 129–138, 1997.