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SCHEDULING FLOWSHOP FOR IMPROVING SUPPLY CHAIN PERFORMANCE

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ABSTRACT

Supply Chain Management (SCM) deals with achieving business performance improvement by integrating source of supply, process and distribution for sales. Scheduling flowshop consider processing a set of job orders on a set of machines following an identical process routing to minimize certain criterion. Scheduling flowshop is the part of process in the supply chain and it traditionally aimed to optimize the resource utilization and delivery performance of job orders. Several research have been reported on scheduling flowshop to minimize the makespan, flow time related costs and tardiness cost. Nevertheless, no research has been done applying value stream management principles while scheduling flowshop. In this paper, problem of scheduling a set of job orders in a flowshop is considered. Complete enumeration, genetic algorithm and dispatching rules have been proposed for solving scheduling flowshop to minimize the sum of variety of opportunity losses for supply chain performance improvements.

Introduction

Supply Chain Management (SCM) is a necessary cornerstone of competitive strategy, increased market share, and shareholder value for most organizations. It is a fundamental concept that has evolved to enable organizations to improve their efficiency and effectiveness in the global and highly competitive environment. The source of supply, manufacturing process and the distribution for sales are the key components in the SCM Network. They need to be effectively designed and operated through integrating these components.

The value–adding manufacturing processes make the final product or service more valuable to the end customer than otherwise it would have been. The traditional supply or value chain includes the complete activities of all the companies involved, whereas the value stream refers only to the specific parts of the firms that actually add value to the specific product or service under consideration. As such the value stream is a far more focused and contingent view of the value-adding process. The rationale underlying in the value stream is to identify waste in individual process and, hence, find an appropriate route to removal, or at least reduction, of this waste. The use of such waste removal to drive competitive advantage inside organizations was pioneered by Toyota's Chief Engineers, Taiichi Ohno (1985), and Shigeo Shingo (1989) and is oriented fundamentally to productivity rather than quality.

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Flowshop is a classical and an important component in the manufacturing process of a Supply Chain Network, Pinedo (2001). The scheduling of flowshop is for their full capacity utilization, on time completion of the job orders and meeting all these goals in minimal cost.

In this paper, the value stream mapping is applied to identify all wastes and then the flowshop scheduling problem is formulated to include the value stream principles. The sum of variety of opportunity losses for Supply Chain performance improvements is minimized by schedules obtained by complete enumeration method, heuristics, dispatching rules and genetic algorithm. Additional computational results are reported to compare the performance of the solution methods.

Value Stream Mapping Principle

Value Stream mapping was initially developed in 1995 with an underlying rationale for the collection and use of the suite of tools as being "to help researchers or practitioners to identify waste in individual value streams and, hence find an appropriate route to its removal", Peter Hines and Nick Rich (1997).

In an internal manufacturing context, there are three types of operation that are undertaken, Monden (1993). These can be categorized into:

1. non-value adding (NVA)
2. necessary but non-value adding (NNVA)
3. value-adding (VA)

NAV is pure waste and involves unnecessary elements which should be eliminated completely. NNVA elements may be wasteful but are necessary under current practices. VA elements involve the conversion or processing of raw materials or semi-finished products through the use of resource capacity. In the following section, these principles are applied to identify wastes in the flowshop to formulate the scheduling problem.

Flowshop Scheduling

The typical flowshop scheduling problem is stated to be determining the optimal schedule of a set of n jobs that need to be manufactured in an m machine flowshop environment to minimize certain criterion. This criterion includes minimization of makespan, sum of flowtime, lateness, tardiness, and so on. Traditionally, these criterions are on the basis of under utilization of resource capacity, late delivery, holding the job for want of processing capacity, etc. Thiagarajan and Rajendran (2005) and Gelders and Sambandam (1978) are the few research considered scheduling flowshop to minimize the sum of weighted earliness, weighted tardiness and weighted flowtime of jobs. Nevertheless, in the context of Supply Chain optimization, these criterions are found to be insufficient and need to be enhanced.

Waste Identification in Flowshop

In general, the job processing, the machine waits for the job (machine idle time or inserted idle time), the job waits for the machine (in-process inventory), and completed job delivery either on time or late are commonly noticed to occur while processing the jobs in the flowshop. In addition, the value of the job keeps changing progressively from the raw material stage to finished job stage while the job is in manufacturing progress in the flowshop. Table 1 shows the list of elements identified in the flowshop processing and their categorization in to value adding and non-value adding.

Table 1: List of identified wastes in the Flowshop and their categorization

Elements	Value-adding (VA)	Non-value adding (NVA)
1. processing	√	-
2. machine idle time	-	√
3. in process inventory	-	√
4. on time delivery	√	-
5. late delivery	-	√

Flowshop Scheduling Problem

The following notations are defined:

n = number of jobs

m = number of machines

R_{ij} = value of material of job i on machine j

p_{ij} = processing time for job i on machine j

d_i = due date for job i

w_i = unit tardiness value

h_i = unit holding value as the percentage of the value of the job

e_j = machine hour rate for machine j

l_j = percentage of opportunity loss of unit hour of machine j

C_i = completion time of job i

I_{ij} = inserted idle time on machine j while job i is processed

W_{ij} = job i waiting time on machine j

T_i = tardiness value of job i = w_i max(0; $C_i - d_i$)

It is proposed to consider the flowshop scheduling criterion defined on the basis of the following value functions:

- Value 1: processing time (p_{ij}) x machine hour rate (e_j)
- Value 2: idle time on machine j x {machine hour rate (e_j) + % of opportunity loss (l_j)}
- Value 3: job waiting time x unit holding value (h_i)
- Value 4: job tardiness value (T_i)

The Flowshop scheduling problem is now stated to determine the optimal schedule of n jobs for processing in an m machine flowshop environment that minimize the sum of values 1 to 4.

In order to solve the above stated problem, the following assumptions are made:

- all jobs arrived simultaneously
- all machines in the flowshop are available without interruption for scheduling

- processing time, due date and values are known constant
- no job preemption is allowed and only permutation schedules are considered for optimization
- job process routings are identical

The above stated flowshop scheduling problem is clearly a NP complete and hence complete enumeration method, heuristics, dispatching rules and genetic algorithms have been proposed to solve the problem.

Solution Methods

The flowshop scheduling problem that minimizes the sum of the value stream mapped wastes was first solved by complete enumeration method to find the optimal value. Then the problem was also solved by a modified heuristic based on Nawaz, et al (1983), EDD dispatching rule, and genetic algorithm based on Sambandam and Bhowmick (2006). The details of these methods were not explained in this paper due to the space limitation. The results obtained by these methods were finally compared to find the efficiency of these methods.

Illustrative Example

Consider 5 jobs for processing in a 4 machine flowshop. Table 2 shows the processing time for each job on each machine (p_{ij}), value of material before start of the processing (R_{i1}), unit holding in-process inventory value (h_i), due date for the job (d_i), unit tardiness value (w_i), and machine hour rate (e_j). The percentage of opportunity loss of unit hour of machine j (l_j) was taken to be 30% and was considered to be time independent.

Table 2: Input data for the illustrative Example (5 Jobs and 4 machines)

Job (i)	p_{i1} (M1)	p_{i2} (M2)	p_{i3} (M3)	p_{i4} (M4)	Raw material value (R_{i1})	Unit holding value (h_i)	Due date (d_i)	Unit tardiness value (w_i)
1	8	10	9	2	100	10%	32	8
2	10	1	1	2	200	10%	35	4
3	1	2	4	8	300	10%	41	3
4	7	5	3	3	400	10%	46	1
5	1	10	1	6	500	10%	52	5
Machine Hour Rate (e_j)	2	5	7	9	-	-	-	-

Suppose a schedule 3-4-2-5-1 obtained by a solution method. The Gantt Chart for this schedule is shown in Figure 1 and the job completion time, job waiting time & machine idle time are calculated and shown in Tables 3, 4 & 5. The details of the calculations of the partial Values 1 to 4 for processing job 3 in the first position of the schedule are shown below:

V_{13} = {Raw material value of job 3 + [processing time of job 3 on machine 1 x machine hour rate of machine 1]} + ...

That is, $V_{13} = \{R_{31} + (p_{31} \times e_1)\} + \{[R_{31} + (p_{31} \times e_1)] + (p_{32} \times e_2)\} + \{[R_{31} + (p_{31} \times e_1) + (p_{32} \times e_2)] + p_{33} \times e_3\} + \{[R_{31} + (p_{31} \times e_1) + (p_{32} \times e_2) + p_{33} \times e_3] + p_{34} \times e_4\}$

$V_{13} = \{R_{31} + (p_{31} \times e_1)\} + \{R_{32} + (p_{32} \times e_2)\} + \{R_{33} + p_{33} \times e_3\} + \{R_{34} + p_{34} \times e_4\}$ ....(1)

By substituting all the known values in equation (1), we get V13 = 1366.0

V_{23} = {Idle time on machine 1 x [machine hour rate (e_1) + % of opportunity loss (l_1)]}

That is, $V_{23} = \{I3_1 \times [e_1 + l_1]\} + \{I_{32} \times [e_2 + l_2]\} + \{I_{33} \times [e_3 + l_3]\} + \{I_{34} \times [e_4 + l_4]\}$........(2)

By substituting all the known values in equation (2), we get V_{23} = 115.7

V_{33} = {job 3 waiting time on machine 1 x unit holding value of job 3 (h_3)} + ……

That is, $V_{33} = \{W_{31} \times h_3\} + \{W_{32} \times h_3\} + \{W_{33} \times h_3\} + \{W_{34} \times h_3\}$............................(3)

By substituting all the known values in equation (3), we get V33 = 0.0

V34 = job tardiness value (T_3)

That is, $V_{34} = w_3 \max\{0, C_3 - d_3\}$…………………… ……………………………….. (4)

By substituting all the known values in equation (4), we get V_{34} = 0.0

Table 6 shows the summary of the results of the above calculations while the job 3 is processed in the first position of the schedule. It may be noticed that the partial total is (1366.0+115.7+0+0) 1481.7.

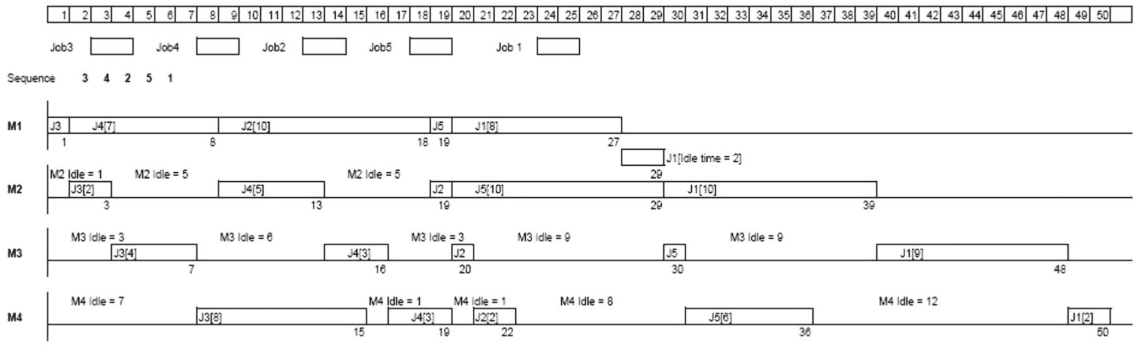

Figure 1: Gantt Chart for the given schedule 3-4-2-5-1

Table 3: Processing time and completion time matrix for the schedule 3-4-2-5-1

Job (i)	pi1 (M1)	pi2 (M2)	pi3 (M3)	pi4 (M4)
3	1^{1}	2^{3}	4^{7}	8^{15}
4	7^{8}	5^{13}	3^{16}	3^{19}
2	10^{18}	1^{19}	1^{20}	2^{22}
5	1^{19}	10^{29}	1^{30}	6^{36}
1	8^{27}	10^{39}	9^{48}	2^{50}

Table 4: Job waiting time matrix for the schedule 3-4-2-5-1

Job (i)	pi1 (M1)	pi2 (M2)	pi3 (M3)	pi4 (M4)
3	0	0	0	0
4	0	0	0	0
2	0	0	0	0
5	0	0	0	0
1	0	2	0	0

Table 5: Machine idle time matrix for the schedule 3-4-2-5-1

Job (i)	p_{i1} (M1)	p_{i2} (M2)	p_{i3} (M3)	p_{i4} (M4)
3	0	1	3	7
4	0	5	6	1
2	0	5	3	1
5	0	0	9	8
1	0	2	9	12

Table 6: Results of summary of calculations while processing job 3 in a given 3-4-2-5-1

Job (3)	Value of the job	Machine hour rate	Job processing time	Holding value	Job idle time	value of the job	M/C idle time	M/C Hr. rate	M/C idle time value
M1	300	2	1	10%	0	302	0	2	0
M2	302	5	2	10%	0	312	1	5	6.5
M3	312	7	4	10%	0	340	3	7	27.3
M4	340	9	8			412	7	9	81.9
						1366			115.7
									1481.7

Similarly, the remaining calculations are carried out to obtain the total value for a given schedule 3-4-2-5-1. Table 7 shows the results of the summary of the calculations for the schedule 3-4-2-5-1. It may be noticed that the total value for the schedule 3-4-2-5-1 is 7974.4.

Table 7: Results of summary of calculations for the given schedule 3-4-2-5-1

Job (i)	C_i	Tardiness cost	M1		M2		M3		M4		Total value
			Value of the job	M/c Idle time value	Value of the job	M/c Idle time value	Value of the job	M/c Idle time value	Value of the job	M/c Idle time value	
3	15	0	302	0	312	6.5	340	27.3	412	81.9	1481.7
4	19	0	414	0	439	32.5	460	54.6	487	11.7	1898.8
2	22	0	220	0	225	32.5	232	27.3	250	11.7	998.5
5	36	0	502	0	552	0	559	81.9	613	93.6	2401.5
1	50	144	116	0	189.2	0	252.2	81.9	270.2	140.4	1193.9
											7974.4

Computational Results

The flowshop scheduling problem that optimizes the values obtained by the value stream mapped wastes was solved by (1) complete enumeration method, (2) heuristics, (3) EDD dispatching rules and (4) genetic algorithm. To measure the computational efficiency of these methods, 150 sample problems were solved with n = 3, 4, 5, 6 & 7 and m = 3, 5 & 8. For each problem the processing time, tardiness weight and machine hour rate were randomly generated respectively from 1 to 20, 1 to 10 and 1 to 10. The value of the material was also randomly selected from the range 1 to 1000. Material value of 10% was taken to be the in-process inventory holding. Machine hour rate of 30% was assumed to be the percentage of opportunity loss. As mentioned in Thiagarajan and Rajandran (2005), the due date for each job was generated by the sum of the processing time plus a random number up to 5n.

To measure the efficiency of each method the following formula was used:

$$\%\,deviation = \frac{Difference\ between\ solution\ by\ complete\ ennumeration\ and\ a\ given\ method}{Solution\ by\ complete\ ennumeration\ method} \times 100$$

The computational results of solving 150 flowshop scheduling problems with value stream management were summarized and shown in Table 8. It may be noticed that 10 problems were solved for each of problem size n x m. It was observed that the optimal solution was obtained by genetic algorithm and therefore its average percentage of deviation was zero for all the problem sizes. The modified NEH heuristic was noted to be performing better than the EDD dispatching rules.

Table 8: Computational results of 150 Flowshop Scheduling

Sr. No.	Problem Size n x m	Average % deviation of Modified NEH Heuristic from enumeration	Average % deviation of EDD dispatching rule from enumeration	Average % deviation of GA from enumeration
1	3 x 3	0.5067	3.0947	0
2	3 x 5	0.2487	2.3426	0
3	3 x 8	1.6357	2.6535	0
4	4 x 3	1.1912	7.7526	0
5	4 x 5	1.1013	10.4198	0
6	4 x 8	0.0144	14.0885	0
7	5 x 3	1.8050	11.1303	0
8	5 x 5	1.5013	14.1706	0
9	5 x 8	0.7312	23.6677	0
10	6 x 3	2.5919	21.2092	0
11	6 x 5	3.0567	25.3073	0
12	6 x 8	3.6137	58.5538	0
13	7 x 3	3.5062	27.6735	0
14	7 x 5	3.3936	53.5619	0
15	7 x 8	3.7114	79.5364	0

Conclusion

Till date, the flowshop scheduling problems generally consider optimizing makespan, mean & weighted flow time, mean & weighted tardiness and combinations of all these measures. In the competitive environment of global business and supply chain approach for improving the business performances, it is not sufficient to deal with the flowshop scheduling with these limited measure of performances. Hence, the value stream mapping was done to identify the list of wastes in the flowshop environment for optimization. The complete enumeration method was applied to find the optimal solution. A heuristic method, EDD dispatching rule and genetic algorithm were also applied to solve the flowshop scheduling problem with VSM. The computational results of solving a sample of 150 problems indicated that the genetic algorithm out performed in all 150 cases.

However, it may be required to test the consistency of these results by solving larger problem dimensions.

Finally, the computational experience revealed that there exists a unique schedule of n jobs for the flowshop scheduling problem with VSM, balancing all wastes. The identification of such unique schedule involved extensive complex computational steps which was quite challenging. Implementing a schedule obtained for a regular measure of performance may lead to inferior results for meeting the supply chain goals. Flowshop schedule obtained by minimizing the sum of value stream mapped wastes will certainly eliminate this gap.

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