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Genetic Algorithm to minimize flowtime in a no-wait flowshop scheduling problem

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Abstract. No-wait flowshop is an important scheduling environment having application in many industries. This paper addresses a no-wait flowshop scheduling problem, where the objective function is to minimise total flowtime. A Genetic Algorithm (GA) optimization approach implemented in a spreadsheet environment is suggested to solve this important class of problem. The proposed algorithm employs a general purpose genetic algorithm which can be customised with ease to address any objective function without modifying the optimization routine. Performance of the proposed approach is compared with eight previously reported algorithms for two sets of benchmark problems. Experimental analysis shows that the performance of the suggested approach is comparable with earlier approaches in terms of quality of solution.

1. Introduction

In a manufacturing environment, scheduling is the efficient use of resources over time. Scheduling is defined as the process of deciding what happens where and when. Any process that defines a subset of *what* x *when* x *where* can be said to "do scheduling" [1]. The objective in any scheduling problem is to determine a method to allocate and sequence the use of the shared resources such that production costs are minimized while satisfying the production constraints. In today's competitive world efficient scheduling schemes / algorithms are a key to achieve high production efficiency.

Flowshop is an important shop model that has been studied widely in the manufacturing community. Since its introduction by Johnson [2] in 1954, flowshop scheduling problem has received considerable attention. A recent detailed survey of flowshop scheduling has been given by Gupta and Stafford Jr [3]. No-wait flowshop is an extension of standard flowshop scheduling problem. No-wait flowshop does not have any intermediate storage between the machines and all jobs are to be processed from first to last machine without any interruptions between the operations. Different industries have no-wait flowshop applications that include concrete ware production, food processing, chemical processing, and pharmaceutical processing. No-wait situation also exist in production lines where the flow of the jobs is continuous and there is no in-process inventory e.g. JIT production lines. Hall and Sriskandarajah [4] gives a thorough analysis of applications and research of no-wait flowshop scheduling problem. No-wait flowshop scheduling problem is considered to be NP-hard even for a two machine case [5].

Minimization of flowtime or makespan are the two most commonly studied objective functions for this class of problem. In this paper minimization of flowtime for no-wait flowshop scheduling problem is considered using genetic algorithm to determine an optimal sequence of jobs.

2. Recent Literature Review

In this section a review of some of the recent studies related to no-wait flowshop is presented. The first instance of flowtime minimization in no-wait flowtime scheduling problem has been reported by Rajendran and Chaudhuri [6]. Since then numerous researchers have attempted to solve the problem with various heuristics. Rajendran and Chaudhuri propose two heuristic algorithms that produce near-optimal solutions for large sized problems.

Li *et al.* [7] present three composite heuristic by integrating forward pair-wise exchange-restart (FPE-R) and FPE with an effective iterative method. Framinan *et al.* [8] present a constructive heuristic for minimizing flowtime in a no-wait flowshop. The heuristic outperforms Pilot-1-Chins heuristic proposed by Fink and Voß [9]. Jarboui *et al.* [10] present a hybrid GA to minimize both flowtime and makespan. The authors use a variable neighborhood search in the last step of the GA to improve upon quality of the solution. Wang *et al.* [11] present three hybrid harmony search (HS) algorithms to minimize flowtime. Well-known benchmark problems are used to carry out computational experiments for the proposed algorithms.

Yagmahan and Yenisey [12] present a multi-objective ant colony system algorithm to minimize both total flowtime and makespan. Gao *et al.* [13] present a discrete harmony search algorithm based on well-known algorithm proposed by Nawaz *et al.* [14] to minimize flowtime. Laha and Sapkal [15] propose an efficient constructive heuristic for solving the problem. Sum of the processing times of a job on the bottleneck machine(s) is used to determine the priority of the job in the initial sequence.

Shafaei *et al.* [16] consider a two stage no-wait flowshop problem with multiple machines at each stage and propose six meta-heuristic algorithms to minimize flowtime. Simulation studies are conducted to evaluate the performance of the proposed approach. Gao *et al.* [17] propose four composite heuristics, improved standard deviation heuristic (ISDH) and improved Bertolissi heuristic (IBH), by combining the standard deviation heuristic [13] and Bertolissi heuristic [18] with the procedure of the constructive heuristic [19]. The authors then propose four composite heuristics, i.e., ISDH and IBH with local search and ISDH and IBH with iteration operator to improve the solutions of the ISDH and IBH. Guang and Junqing [20] propose an evolved discrete harmony search (EDHS) to minimize maximum completion time, total flowtime and total tardiness.

Gupta [21] present an algorithm to minimize weighted flowtime when processing times are uncertain. Gupta [22] also present an algorithm to minimize flowtime in two machine no-wait problem under the constraint of machine availability. Nagano *et al.* [23] present a GA and cluster search based evolutionary clustering algorithm for no-wait flowshop where setup times of jobs are separate from the processing time. Sapkal and Laha [24] also present an efficient heuristic method to minimize total flowtime. Laha and Sapkal [15] method is used to determine the job priority in the initial sequence.

3. Problems & Assumptions

A flowshop is a multi-stage scheduling where jobs are required to be processed through different stages. The no-wait flowshop problem is defined as: Each of the n jobs from a set $J = \{1, 2,....., n\}$ are required to be processed on m $\{M = 1, 2,....., n\}$ machines. Each job has m operations (o_{j1}, o_{j2},...., o_{jm}). All operations of job j are to be processed on machines without interruptions i.e., the earliest start time operation o_{jM+1} must be equal to completion time of o_{jM}. In other words there must not be any waiting between successive operations of job n. All jobs must follow a same sequence of operations on all the machines. The problem then is to find job sequence (permutation schedules) that minimizes total flowtime of n jobs.

Additionally following assumptions are considered in this research: (a) All jobs are available at the start of the planning horizon; (b) An operation once started cannot be interrupted; (c) All processing times are known and constant; (d) Setup time for setting up of machine to process a particular operation is included in the operation time; (e) Transportation time of jobs between machines is negligible; (f) At any given time, each machine can process only one job; (g) None of the machine can process more than one operation at a time; and (h) The machines does not have any intermediate storage for the unprocessed jobs.

4. Genetic Algorithm Details

Genetic algorithms are stochastic search technique inspired by natural evolution. The search process GAs are guided by Darwin's survival of the fittest principles. GAs are therefore able to traverse a large search space. GAs were first invented by Holland [25] and his colleagues in 1975 at the University of Michigan.

First application of GAs in job scheduling domain has been given by Davis [26]. In this research, GA optimization routine is implemented in a spreadsheet environment. We employ a commercial general purpose GA by Palisade [27], that works as an add-in to Microsoft Excel® spreadsheet. The schematic diagram for the integration of Microsoft Excel and GA are given in Figure 1.

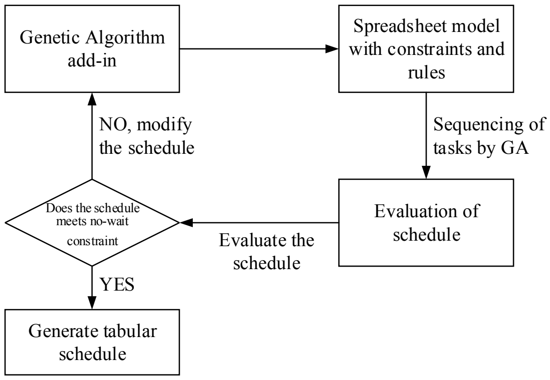

Figure 1. Spreadsheet - Genetic Algorithm Integration

5. Implementation Details

'No-wait' model proposed in this paper works in two phases. First phase calculates the delay in the starting of job *p* after *q*. Second stage delays job *q* after *p* by the delay factor that is calculated in first phase. This delay thus yields a no-wait schedule. The minimum delay in the start of job *q* after *p* i.e., *F(p, q)* is calculated by the approach proposed by Reddi and Ramamoorthy [28]. Thus the minimum delay time between the completion of job J_p and the initiation of J_q, then *F(p, q)* is given by:

$$F(p, q) = \max (t_{2,p} - t_{1,q}, t_{2,p} + t_{3,p} - (t_{1,q} + t_{2,q}),\ldots, t_{2,p} + t_{3,p} + t_{4,p} +\ldots+t_{m,p} - (t_{1,q} + t_{2,q} +\ldots+ t_{m-1,q}),0)$$

$$= \max_k \left(\sum_{i=2}^{k} t_{i,p} - \sum_{i=1}^{k-1} t_{i,q}, 0\right), \qquad 2 \le k \le m$$

The use of above equation is illustrated with the help of a sample problem. Consider 5-job 3-machine problem given in Table 1.

Table 1. Numerical Example Data

Machine	Processing Times				
	Job 1	**Job 2**	**Job 3**	**Job 4**	**Job 5**
Mch1	*3*	*4*	*1*	*1*	*4*
Mch2	*2*	*5*	*4*	*3*	*3*
Mch3	*4*	*3*	*5*	*2*	*7*

The Gantt chart for the data given in Table 1 for a job sequence of 5-3-2-1-4 is as show in Figure 2.

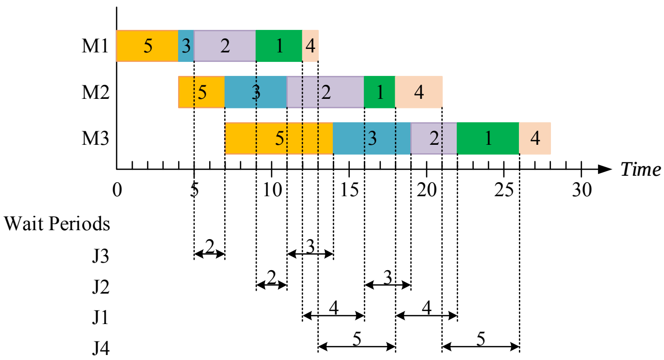

Figure 2. Gantt chart for sequence of job 5-3-2-1-4 and corresponding wait periods

The start delay for each of the job is calculated as describe above. By delaying the start of job *q* after job *p* for the schedule in Figure 2 by duration *F*(*p*, *q*) would result in a no-wait schedule as given in Figure 3.

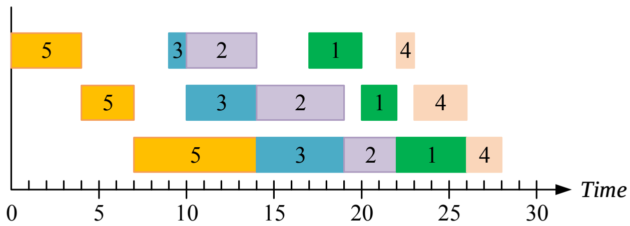

Figure 3. No-wait schedule for job sequence 5-3-2-1-4

6. Experimental Results & Comparisons

To test the performance of the proposed GA experimental analysis was carried out. The results of the proposed approach are compared with other heuristic solutions taken from the literature for well-known benchmark problems provided by Taillard [29]. The benchmarks consists of two set of problems with ten problems each for $n=20$ and $m=5$ and *10*. Following heuristics are used to compare the performance of proposed approach:

- ISDH : Improved Standard Deviation heuristic based on Gao *et al.* [13]
- IBH : Improved Bertolissi heuristic based on Bertolissi [18]
- Dipak : Constructive heuristic by Laha and Chakraborty [19]
- AA_Omega : Heuristic algorithm by Aldowaisan and Allahverdi [30]
- ISDHLS : Improved Standard Deviation with local search heuristic by Gao *et al.* [17]
- IBHLS : Improved Bertolissi heuristic by Gao *et al.* [17]
- ISDHIter : Improved Standard Deviation with with iteration operator Gao *et al.* [17]
- IBHIter : Improved Bertolissi heuristic with iteration operator Gao *et al.* [17]

The best values for all above heuristics for $n=20$, $m=5$ and $n=20$, $m=10$ are given in Table 2 and Table 3 respectively. The results are based on forty runs for each instance. For $n=20$, $m=5$, the proposed the performance of GA was superior for 7 out of 10 problems while for $n=20$, $m=10$ the results were better for all instances as compared to eight heuristics mentioned above.

7. Conclusions

In this paper we presented a genetic algorithm approach for no-wait flowshop scheduling problem where the objective was to minimize total flowtime. The problem is categorized as NP-hard even for a two machine case. The GA routine is implemented in a spreadsheet environment. The proposed approach implements a general purpose GA for the optimization routine and as is easily customizable to address any objective function without modifying the basic optimization routine. The experimental results show that the proposed approach produced superior results for 17 out of 20 instances.

Table 2. Best flowtime values for *n=20*, *m=5*

Instance	ISDH	IBH	Dipak	AA_ Omega	ISDHLS	IBHLS	ISDHIter	IBHIter	GA	%age Improve
1	16553	16562	16421	16357	16414	16230	16381	16302	15674	3.4258
2	16749	16435	16551	16268	16164	16172	16220	16230	17250	-6.7186
3	15160	15197	14959	15258	14943	15024	15051	15018	15855	-6.1032
4	18989	18864	19048	18644	18732	18679	18788	18782	17970	3.6151
5	17293	16587	16570	16353	16684	16475	16385	16467	15317	6.3352
6	16268	15841	15974	15669	16109	15832	15620	15841	15501	0.7618
7	16302	16533	16538	16116	15990	15898	16117	16312	15693	1.2895
8	17836	17509	17277	17528	17403	17499	17340	17421	15955	7.6518
9	16802	17096	17186	16760	16551	16736	16802	16588	16394	0.9486
10	15693	15897	15776	15688	15785	15051	15208	15373	15329	-1.8471

Table 3. Best flowtime values for *n=20*, *m=10*

Instance	ISDH	IBH	Dipak	AA_ Omega	ISDHLS	IBHLS	ISDHIter	IBHIter	GA	%age Improve
1	27043	25664	26431	25410	26582	25657	25410	25664	25319	0.3581
2	26976	27037	26794	26847	26748	26774	26773	26586	26363	0.8388
3	25033	24509	24856	24377	24230	24509	24260	24277	22910	5.4478
4	23323	23353	23284	22905	22976	23120	22905	23138	22243	2.8902
5	24056	24185	23824	23779	23611	23838	24056	23998	23191	1.7788
6	23503	23416	23319	23743	23187	23016	23503	23380	22011	4.3665
7	24371	24236	24574	24344	24264	23967	24372	24500	21939	8.4616
8	24614	24416	24878	24294	24294	24315	24294	24294	24265	0.1194
9	24947	25128	25535	25799	25040	24663	24771	25107	23522	4.6264
10	27043	25664	26431	25410	26582	25657	25410	25664	25319	0.3581

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