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Solving Flow Shop Scheduling Problems Using a Hybrid Genetic Scatter Search Algorithm

R. Hariharan and R.J. Golden Renjith Nimal

Mechanical Engineering, Bharath University, India

Abstract: In this paper we consider n-jobs, m-machines permutation flow shop scheduling problems. Flow shop scheduling is one of the most important combinational optimization problems. The permutation flow shop scheduling problems are NP-Hard (Non deterministic Polynomial time Hard). Hence many heuristics and meta- heuristics were addressed in the literature to solve these problems. In this paper a hybrid genetic scatter search algorithm (HGSSA) is presented to minimize the makespan for the permutation flow shop scheduling problems. An effective constructive heuristics is incorporated with the initial solutions to obtain the optimal or near-optimal solutions rapidly. The performance of the proposed algorithm has been tested with the benchmark problems addressed in the literature. The results are compared with some other meta-heuristics algorithms. The results show that the proposed algorithm is efficient in producing optimal or near-optimal solutions.

Key words: Flow shop · Scheduling · Makespan · NP-hard · Heuristics · Meta-heuristics · Hybrid genetic scatter search algorithm (HGSSA)

INTRODUCTION

Scheduling is an important decision making process in Operations Management. Pinedo [1] addressed the different types of scheduling problems. In this paper, we consider the flow shop scheduling problems with makespan minimization objective. The flow shop scheduling problem was first proposed by Johnson [2]. The flow shop scheduling problem has been proved to be NP-hard. Researchers have developed exact methods, heuristics and meta-heuristics to solve the flow shop scheduling problems. Corwin *et al*. [3] developed a dynamic programming model to solve the flow shop scheduling problems with sequence dependent setup times. A branch and bound algorithm was proposed by Baptiste and H guny [4] to minimize the makespan in a no-idle flow shop scheduling problems. Some constructive heuristics were developed by Campbell *et al*. [5], Dannenbring [6] and Nawaz *et al*. [7] to solve the flow shop scheduling problems. King and Spachis [8] proposed some heuristics for solving the flow shop scheduling problems. Rajendran and Chaudhri [9] also developed several heuristics to solve the flow shop scheduling problems. A genetic algorithm (GA) was proposed to solve the flow shop scheduling problems by Reeves [10]. Murata *et al*. [11] solved the flow shop scheduling problems using the GA. Nowicki and Smutnicki [12] applied the tabu search (TS algorithm for solve flow shop scheduling problems with parallel machines. Reza Hejazi and Saghafian [13] also addressed a review on the flow shop scheduling problems with the makespan criterion. Ruiz and Maroto [14] presented a comprehensive review of the different heuristics used to solve the flow shop scheduling problems. They also evaluated the performance of the different heuristics. A differential evolution algorithm was addressed to solve the flow shop scheduling problems to minimize makespan by Onwubolu and Davendra [15]. A particle swarm optimization algorithm was developed for solving the flow shop scheduling problems by Liao [16]. Liu *et al*. [17] presented an effective hybrid particle swarm optimization algorithm for solving the no-wait flow shop scheduling problem with makespan criterion. A simple and effective iterated greedy algorithm was suggested for the permutation flow shop scheduling problem by Ruiz and Stutzle [18]. Ying and Lin [19] proposed an ant colony system heuristic for solving the non-permutation flow shop scheduling problems. A greedy heuristic algorithm

Corresponding Author: R. Hariharan, Mechanical Engineering, Bharath University, India.

was addressed by Baraz and Mosheiov [20] to minimize the makespan for no- idle flow shop scheduling problems. Pan *et al*. [21] developed a hybrid discrete particle swarm optimization algorithm for solving the no-wait flow shop scheduling problem with makespan criterion. Qian *et al*. [22] proposed a differential evolution (DE) algorithm to solve the flow shop scheduling problems to minimize the makespan. Jarboui *et al*. [23] proposed a hybrid GA to solve the flow shop scheduling problems. Akhshabi *et al*. [24] proposed a parallel genetic algorithm to minimize the makespan of flow shop scheduling problems. Lin *et al*. [25] proposed a Multi-level genetic algorithm to minimize the makespan of a resource constrained re-entrant flow shop scheduling problems. They proved that the proposed algorithm was more effective than the simulated annealing (SA) algorithm. Recently, Fatih Tasgetiren *et al*. [26] proposed a variable iterated greedy algorithm (IG) with differential evolution to solve the no-idle permutation flow shop scheduling problems to minimize the makespan and total flow time. Scatter search (SS) algorithm was developed by Glover [27]. The détails of SS algorithm can be found in [28]. Noorul Haq *et al*. [29] addressed a SS algorithm to solve the flow shop scheduling problems. Rahimi-Vahed *et al*. [30] proposed a multi-objective scatter search algorithm to solve the mixed–model assembly line sequencing problem. Rahimi-Vahed *et al*. [31] also addressed a multi-objective scatter search algorithm to solve the flow shop scheduling problems. Saravanan *et al*. [32] evaluated the performance of the scatter search algorithm to solve the flow shop scheduling problems to minimize the makespan. Saravanan *et al*. [33] also applied the scatter search algorithm to solve the job shop scheduling problems. Jose A. Egea *et al*. [34] addressed an improved scatter search algorithm for the global optimization of computationally expensive dynamic models. Ranjbar *et al*. [35] developed a hybrid SS algorithm to solve the project scheduling problems. Sari *et al*. [36] evaluated the performance of the scatter search and genetic algorithm to solve the resource constrained project scheduling problems. Ali M. Sagheer *et al*. [37] improved the performance of the scatter search algorithm using the bees algorithm. Jue Wang *et al*. [38] proposed a rough set and scatter search metaheuristic based feature selection for credit scoring. Tao Zhang *et al*. [39] proposed a scatter search algorithm to solve the vehicle routing problems with simultaneous pick-ups and deliveries. They also developed a generic genetic algorithm approach and used as a reference for performance comparison. Ying Xu and Rong Qu [40] developed a hybrid scatter search algorithm to solve the delay-constrained multicast routing problems. Hence, in this paper we propose a hybrid genetic scatter search algorithm to solve the flow shop scheduling problems. The rest of the paper is organised as follows. The flow shop scheduling problem is defined in section 2. The proposed hybrid genetic scatter search algorithm is presented in section 3. Computational results will be discussed in section 4. Section 5 presents the conclusion and future research opportunities.

Problem Definition: We consider n jobs to be scheduled. The flow shop scheduling environment consists of m machines in series. Each job must be processed through the machines in a particular sequence. The objective of this paper is to minimize the makespan. Makespan is defined as the completion time of the last job to leave the system. Makespan minimization is important to reduce production time and improve the system utilization. The layout of the flow shop environment is given in Figure 1.

The following parameters are considered in this paper.

n = Number of jobs
m = Number of machines
j = Index for jobs
i = Index for machines
PT_{ij} = Processing time of job j on machine i
C_{ij} = Completion time of job i on machine j
C_{im} = Completion time of job i on machine m
C_{max} = Makespan value
C^* = Optimal makespan value
R_j = Ready time of job j
S_{ij} = Starting time of job i on machine j

We formulate a mathematical model to solve this problem as follows.

Minimize: C_{max}
Subject to: $Cmax \geq Cim$ for all i,
$Cij = Sij + PTij$ for all i and j,
$Sij \geq Rj$ for all i,
$Cij \geq Ci, j - 1 + PTij$ for all i,
$Cij \geq 0$ *for all i, j.*

To solve the problems we consider the following assumptions.

- All the jobs and machines are available at time zero.
- Each machine can processes only one job at a time.

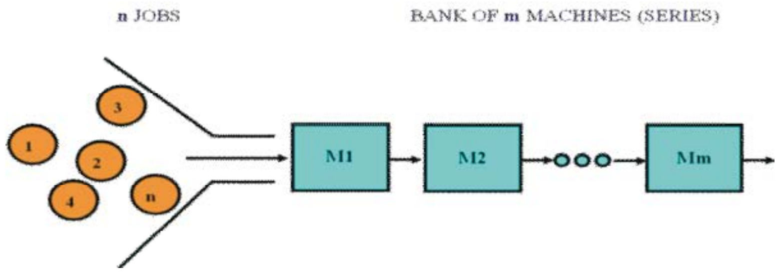

Fig. 1: Layout of a flow shop environment

- Each job is to be processed on one machine at a time.
- The operations are not pre-emptable.
- The processing times are known and the values are fixed.
- The set-up times of the jobs are included in the processing time and do not depend on the sequence of operations.
- The operating sequences of the jobs are the same on every machine and the common sequence has to be determined.

Hybrid Genetic Scatter Search Algorithm: In this paper, we hybrid the genetic algorithm and the scatter search algorithm to minimize the makespan of flow shop scheduling problems.

Genetic Algorithm (GA): GA is a population based meta-heuristic algorithm developed by Holland [41]. It is based on the process of natural selection and natural genetics.

The steps in simple genetic algorithm are given below.

- Generate an initial population of random solutions
- Evaluate the fitness of each solution
- Develop a new population using the following genetic operators
- Selection
- Cross over
- Mutation

Scatter Search Algorithm:

- A diversification generation method to generate a collection of diverse trial solutions, using an arbitrary trial solution as an input.
- An improvement method to transform a trial solution into one or more enhanced trial solutions.
- A reference set update method to build and maintain a reference set consisting of the b ‘‘best’’ solutions.

A subset generation method to operate on the reference set, to produce a subset of its solutions as a basis for creating combined solutions.

A solution combination method to transform a given subset of solutions produced by the subset generation method into one or more combined solution vectors.

Hybrid Genetic Scatter Search (HGSS) Algorithm: In this paper, we hybrid two genetic operators with the scatter search algorithm.

The steps in HGSS algorithm is described below.

Step 1: Define the parameters of the HGSS algorithm including the initial population size, reference set size, size of the high quality solutions and diverse solutions, crossover probability, mutation probability, fitness function and the number of generations.

Step 2: Generate a population of initial solutions randomly.

Step 3: Evaluate the makespan of all the solutions generated in the previous step.

Step 4: A reference set that consists of both high quality solutions and diverse solutions is built based on the results obtained in the previous step.

Step 5: Select two parents by the tournament selection [41].

Step 6: New off springs are produced by the Cross over operator.

Step 7: A swap mutation is carried out to avoid the solutions to be trapped in local optima.

Step 8: New solutions are developed.

Step 9: The new solutions are evaluated.

Table 1: Parameters Ozf Hgss Algorithm

Parameters	Value
Population size	20
Selection method	Tournament S
Reference set size	10
Size of the high quality Solutions	5
Size of the diverse solutions	5
Crossover probability	0.9
Mutation probability	0.03
Number of generations	500

Table 2: Bench Mark Problem

Problem no.	Problem
1	flcmax_20_15_4
2	flcmax_20_15_10
3	flcmax_20_20_1
4	flcmax_20_20_3
5	flcmax_20_20_10
6	flcmax_30_15_4
7	flcmax_30_15_6
8	flcmax_30_15_9
9	flcmax_30_20_1
10	flcmax_30_20_2
11	flcmax_30_20_10
12	flcmax_40_15_2
13	flcmax_40_15_5
14	flcmax_40_15_8
15	flcmax_40_20_5
16	flcmax_40_20_9
17	flcmax_50_15_1
18	flcmax_50_15_2
19	flcmax_50_15_6
20	flcmax_50_15_6

Table 3: Makespan Comparison of the Benchmark Problems

			C^*	C_{max}		
Problem no.	n	m	Lower Bound	Upper Bound	ACO [19]	HGSS
1	20	15	2997	3779	3786	3547
2	20	15	3420	4302	4265	4108
3	20	20	3776	4821	4819	4550
4	20	20	3758	4779	4723	4357
5	20	20	3823	4717	4715	4494
6	30	15	4080	5304	5284	4905
7	30	15	4184	5147	5149	4930
8	30	15	4022	5079	5075	4868
9	30	20	4772	6037	5989	5722
10	30	20	4757	5822	5840	5683
11	30	20	4899	6095	5923	5705
12	40	15	5290	6506	6532	6281
13	40	15	5560	6986	6972	5962
14	40	15	5576	6783	6771	6579
15	40	20	6011	7219	7217	6683
16	40	20	5998	7528	7496	7161
17	50	15	6198	7416	7402	6984
18	50	15	6531	7750	7712	7238
19	50	15	6290	7673	7631	7215
20	50	15	6312	7548	7558	7330

Step 10: The reference set is updated and the steps 6-10 are repeated until the stopping criterion is met.

Computationals Results: The proposed algorithm was coded in C++ and run on a PC with an Intel Core Duo 2.4GHz CPU, 2GB RAM, running Windows XP. The parameters of the proposed algorithm are given in Table 1.

To study the performance of the proposed algorithm, we consider the benchmark problems studied by Demirkol *et al*. [42]. We select 20 benchmark problems randomly. The test problems involve two machine number values (m=15, 20) and four job number values (n=20, 30, 40, 50). The results are compared with the upper bound determined by Demirkol *et al*. [42] and an ant colony optimization meta-heuristic (MHD-ACS) proposed by Ying and Lin [19]. The benchmark problem details are presented in Table 2 and the result comparison is presented in Table 3.

CONCLUSIONS

We present a hybrid genetic scatter search algorithm to minimize the makespan for permutation flow shop scheduling problems. The proposed algorithm has been tested over a set of benchmark problems from the literature and the results have been compared with other meta-heuristics in the literature. It is concluded the hybrid genetic scatter search algorithm provides better results than other metaheuristic algorithm. This work may be extended in many directions. The algorithm may be extended to solve the scheduling problems with multiple objectives. The algorithm can also be applied to solve real industrial scheduling problems. The research may also be conducted for scheduling problems with due date related performance measures and problems with the inclusion of set up time may be some possible scope of this work.

REFERENCES

1. Pinedo, M., 1995. “Scheduling Theory, Algorithms and Systems“, 2nd ed., Prentice-Hall, Englewood Clifls.
2. Johnson, S., 1954. “Optimal two- and three-stage production schedules with setup times included’, Naval Research Logistics Quarterly, 1(1): 61-68.
3. Corwin, B.D. and A.O. Esogbue, 1974. “Two machine flow shop scheduling problems with sequence dependent setup times: a dynamic programming approach” Naval Research Logistics Quarterly, 21: 515-524.

4. Baptiste, P. and L.K. Hguny, 1997. "A branch and bound algorithm for the F/no-idle/Cmax", Proc. of the International Conference on Industrial Engineering and Production Management, pp: 429-438.
5. Campbell, H., R. Dudek and M. Smith, 1970. "A Heuristic Algorithm for the n Job m Machine Sequencing Problem" Management Science, 16(10): 630-637.
6. Dannenbring, D., 1977. An Evaluation of Flow Shop Sequencing Heuristics" Management Science, 23(11): 1174-1182.
7. Ruiz, R. and C. Maroto, 2005. "A comprehensive review and evaluation of flowshop heuristics", European Journal of Operational Research, 165(2): 479-494.
8. Onwubolu, G. and D. Davendra, 2006. "Scheduling flow shops using differential evolution algorithm", European Journal of Operational Research, 171(2): 674-692.
9. Akhshabi, M., J. Haddadnia and M. Akhshabi, 2012. "Solving flow shop scheduling problemusing a parallel genetic algorithm", Procedia Technology, 1: 351-355.
10. Lin, D., *et al*., 2013."Multi-level genetic algorithm for the resource-constrained re-entrant scheduling problem in the flow shop", Engineering Applications of Artificial Intelligence, Available: http://dx.doi.org/10.1016/j.engappai.2012.10.006i.
11. Fatih Tasgetiren, M., Quan-Ke Pan, P.N. Suganthan and Ozge Buyukdagli, 2013. "A Variable Iterated Greedy Algorithm with Differential Evolution for the No-Idle Permutation Flowshop Scheduling Problem", Computers and Operations Research, http://dx.doi.org/ 10.1016/j.cor. 2013.01.005.
12. Glover, F., 1977. "Heuristics for integer programming using surrogate constraints", Decision Sciences, 8(1): 156-166.
13. Glover, F., M. Laguna and R. Martí, 2000. "Fundamentals of Scatter Search and Path Re linking", Control and Cybernetics, 29(3): 653-684.
14. Noorul Haq, A., M. Saravanan, A.R. Vivekraj and T. Prasad, 2006. "A scatter search approach for general flowshop scheduling problem", International Journal of Advanced Manufacturing Technology, 31(7/8): 731-736.
15. Rahimi-Vahed, A.R., M. Rabbani, R. Tavakkoli-Moghaddam, S.A. Torabi and F. Jolai, 2007. "A multi-objective scatter search for a mixed–model assembly line sequencing problem", Advanced Engineering Informatics, 21(1): 85-99.
16. Rahimi-Vahed, A.R., B. Javadi, M. Rabbani and R. Tavakkoli-Moghaddam, 2008. "A multi-objective scatter search for a bi-criteria no-wait flow shop scheduling problem", Engineering Optimization, 40(4): 331-346.
17. Saravanan, M., A. Noorul Haq, A.R. Vivekraj and T. Prasad, "Performance evaluation of the scatter search method for permutation flowshop sequencing problems", International Journal of Advanced Manufacturing Technology, 37(11/12): 1200-1208.
18. Saravanan, M. and A. Noorul Haq, 2010. "A scatter search algorithm for scheduling optimisation of job shop problems", International Journal of Product Development, 10(1/2/3): 259-272.
19. Jose A. Egea, Emmanuel Vazquez, R. Julio Banga and Rafael Martí, 2009. " Improved scatter search for the global optimization of computationally expensive dynamic models", Journal of Global Optimization, 43: 175-190.
20. Ranjbar, M., B. De Reyck and F. Kianfar, 2009. "A hybrid scatter search for the discrete time/resource trade-off problem in project scheduling", European Journal of Operational Research, 193(1): 35-48.
21. Sari, T., V. Cakir, S. Kilic and E. Ece, 2011. "Evaluation of Scatter Search and Genetic Algorithm at Resource Constrained Project Scheduling Problems", in Proc. Of the International Conference on Intelligent Engineering Systems.
22. Ali Sagheer, M., T. Ahmed Sadiq and S. Mohammed Ibrahim, 2012. "Improvement of Scatter Search Using Bees Algorithm", Proc. of the International Conference on Signal Processing and Communication Systems.
23. Jue Wang, Abdel-Rahman Hedar, Shouyang Wang and Jian Ma, 2012. "Rough set and scatter search meta heuristic based feature selection for credit scoring", Expert Systems with Applications, 39: 6123-6128.
24. Tao Zhang, W.A. Chaovalitwongse and Yuejie Zhang, 2012. "Scatter search for the stochastic travel-time vehicle routing problem with simultaneous pick-ups and deliveries", Expert Systems with Applications, 39: 6123-6128.

25. Ying Xu and Rong Qu, 2012. ”A hybrid scatter search meta-heuristic for delay-constrained, multicast routing problems”, Springer Science & Business Media, 36: 229-241.
26. Holland, J.H., 1975. “Adaptation in natural and artificial systems”. Ann Arbor: University of Michigan Press.
27. Demirkol, E., S. Mehta and R. Uzsoy, 1998. ”Benchmarks for shop scheduling problems”, European Journal of Operational Research, 109(1): 137-141.