Hybrid Genetic Algorithm for Multicriteria Scheduling with Sequence Dependent Set up Time

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Abstract

In this work, multicriteria decision making objective for flow shop scheduling with sequence dependent set up time and due dates have been developed. Multicriteria decision making objective includes total tardiness, total earliness and makespan simultaneously which is very effective decision making for scheduling jobs in modern manufacturing environment. As problem of flow shop scheduling is NP hard and to solve this in a reasonable time, four Special heuristics (SH) based Hybrid Genetic Algorithm (HGA) have also been developed for proposed multicriteria objective function. A computational analysis upto 200 jobs and 20 machines problems has been conducted to evaluate the performance of four HGA's. The analysis showed the superiority of SH1 based HGA for small size and SH3 based HGA for large size problem for multicriteria flow shop scheduling with sequence dependent set up time and due dates.

Keywords: Flow shop scheduling, Genetic algorithm, Sequence dependent set up time, Total tardiness, Total earliness, makespan

1. INTRODUCTION

Scheduling in manufacturing systems is typically associated with allocating a set of jobs on a set of machines in order to achieve some objectives. It is a decision making process that concerns the allocation of limited resources to a set of tasks for optimizing one or more objectives. Manufacturing system is classified as job shop and flow shop and in the present work; we have dealt with flow shop. In a job shop, set of jobs is to be scheduled on a set of machines and there is no restriction of similar route on the jobs to follow, however in flow shop environment all the jobs have to follow the similar route. Classical flow shop scheduling problems are mainly concerned with completion time related objectives (e.g. flow time and makespan) and aims to reduce production time and enhance productivity and facility utilization. In modern manufacturing and operations management, on time delivery is a significant factor as for the survival in the competitive markets and effective scheduling becomes very important in order to meet customer requirements as rapidly as possible while maximizing the productivity and facility utilization. Therefore, there is a need of scheduling system which includes multicriteria decisions like makespan, total flow time, earliness, tardiness etc.

Also, flow shop scheduling problems including sequence dependent set up time (SDST) have been considered the most renowned problems in the area of scheduling. Ali Allahverdi et al [1] investigated the survey of flow shop scheduling problems with set up times and concluded that considering flow shop scheduling problems is to obtain remarkable savings when setup times are included in scheduling. Sequence dependent setup times are usually found in the condition where the multipurpose facility is available on multipurpose machine. Flow shop scheduling with sequence dependent set up time can be found in many industrial systems like textile industry, stamping plants, chemical, printing, pharmaceutical and automobile industry etc. Several researchers have considered the problem of flow shop scheduling with single criterion and very few have dealt with multicriterion decision making including sequence dependent set up.

The scheduling literature also revealed that the research on flow shop scheduling is mainly focused on bicriteria without considering sequence dependent set up time .Very few considered flow shop scheduling including sequence dependent set up time with multicriteria. Rajendran [2] has implemented a heuristic for flow shop scheduling with multiple objectives of optimizing makespan, total flow time and idle time for machines. The heuristic preference relation had been proposed which was used as the basis to restrict the search for possible improvement in the multiple objectives. Ravindran et al. [3] proposed three heuristic similar to NEH for flow shop scheduling with multiple objectives of makespan and total flow time together and concluded that proposed three heuristic yields good results than the Rajendran heuristic CR[2].Gupta et al.[4] considered flow shop scheduling problem for minimising total flow time subject to the condition that the makespan of the schedule is minimum. Sayin and Karabati [5] minimized makespan and sum of completion times simultaneously in two machines flow shop scheduling environment. Branch and bound procedure was developed that iteratively solved single objective scheduling problems until the set of efficient solutions was completely enumerated. Danneberg et al. [6] addressed the permutation flow shop scheduling problem with setup times and considered makespan as well as the weighted sum of the completion times of the jobs as objective function. For solving such a problem, they also proposed and compared various constructive and iterative algorithms. Toktas et al. [7] considered the two machine flow shop scheduling by minimizing makespan and maximum earliness simultaneously. They developed a branch & bound and a heuristic procedure that generates all efficient solutions with respect to two criteria. Ponnambalam et al. [8] proposed a TSP GA multiobjective algorithm for flow shop scheduling, where a weighted sum of multiple objectives (i.e. minimizing makespan, mean flow time and machine idle time) was used. The proposed algorithm showed superiority which when applied to benchmark problems available in the OR-Library. Loukil et al. [9] proposed multiobjective simulated annealing algorithm to tackle the multiobjective production scheduling problems. They considered seven possible objective functions (the mean weighted completion time, the mean weighted tardiness, the mean weighted earliness, the maximum completion time (makespan), the maximum tardiness, the maximum earliness, the number of tardy jobs). They claimed that the proposed multiobjective simulated annealing algorithm was able to solve any subset of seven possible objective functions. Fred Choobineh et al. [10] proposed tabu search heuristic with makespan, weighted tardiness and number of tardy jobs simultaneously including sequence dependent setup for n jobs on a single machine. They illustrated that as the problem size increases, the results provided by the proposed heuristic was optimal or nearer to optimal solutions in a reasonable time for multiobjective fitness function considered. Rahimi Vahed and Mirghorbani [11] developed multi objective particle swarm optimization for flow shop scheduling problem to minimize the weighted mean completion time and weighted mean tardiness simultaneously. They concluded that for large sized problem, the developed algorithm was more effective from genetic algorithm. Noorul Haq and Radha Ramanan[12]used Artificial Neural Network (ANN) for minimizing bicriteria of makespan and total flow time in flow shop scheduling environment and concluded that performance of ANN approach is better than constructive or improvement heuristics. Lockett and Muhlemann [13] proposed branch and bound algorithm for scheduling jobs with sequence dependent setup times on a single processor to minimize the total number of tool changes. Proposed algorithm was suitable for only small problems which was the major limitation of that algorithm. Gowrishankar et al. [14] considered *m*-machine flow shop scheduling with minimizing variance of completion times of jobs and also sum of squares of deviations of the job completion times from a common due date. Blazewicz et al. [15] proposed different solution procedures for flow shop scheduling for two machine problem with a common due date and weighted latework criterion. Eren [16] considered a bicriteria *m*-machine flowshop scheduling with sequence dependent setup times with objective of minimizing the weighted sum of total completion time and makespan. He developed the special heuristics for fitness function considered and proved that the special heuristic for all number of jobs and machines values was more effective than the others. Erenay et al. [17] solved bicriteria scheduling problem with minimizing the number of tardy jobs and average flowtime on a single machine. They proposed four new heuristics for scheduling problem and concluded that the proposed beam search heuristics find efficient schedules and performed better than the existing heuristics available in the literature. Naderi et al. [18] minimized makespan and maximum tardiness in SDST flow shop scheduling with local search based hybridized the simulated annealing to promote the quality of final solution.

Therefore, in modern manufacturing system, production cost must be reduced in order to survive in this dynamic environment which can be done by effective utilisation of all the resources and completion of production in shorter time to increase the productivity also simultaneously considering due and early dates of the job. As minimisation of makespan with not meeting the due date is of no use for an industry since there is loss of market competitiveness, loss of customer, tardiness and earliness penalty etc.

Hence, for the today's need, we have considered the flowshop scheduling problem with sequence dependent set up time with tricriteria of weighted sum of total tardiness, total earliness and makespan which is very effective decision making in order to achieve maximum utilization of resources in respect of increasing the productivity and meeting the due dates so as the customer good will and satisfaction. We also proposed hybrid genetic algorithm in which initial seed sequence is obtained from heuristic similar to NEH [19]. As classical NEH considered processing times for makespan minimization and proposed heuristic also works on multicriteria objective function (i.e. weighted sum of total tardiness, total earliness and makespan).

2. STATEMENT OF PROBLEM

We have considered the flow shop scheduling problem with sequence dependent setup times and due dates associated to jobs in which the objective is to minimize the multicriteria decision making for manufacturing system including total tardiness, total earliness and makespan simultaneously. Various assumptions, parameters and multicriteria objective function considered has been illustrated below:

Assumptions

- Machines never break down and are available throughout the scheduling period.
- All the jobs and machines are available at time Zero.
- All processing time on the machine are known, deterministic and finite.
- Set up times for operations are sequence dependent and are not included in processing times
- Pre-emption is not allowed.
- Each machine is continuously available for assignment, without significant division of the scale into shifts or days and without any breakdown or maintenance.
- The first machine is assumed to be ready whichever and whatever job is to be processed on it first.
- Machines may be idle.
- Splitting of job or job cancellation is not allowed.
- It is associated with each job on each machine i.e. the time required to bring a given machine to a state, which allows the next job to commence and are immobilized to the machines.

Parameters

i	Index for Machines	$i=1,2,3........m$	C_j	Completion time of job 'j'
j	Index for Jobs	$j=1,2,3........n$	d_j	Due date of job'j'
α	Weight for Total tardiness	$\alpha \geq 0$	T_j	Tardiness of job 'j'
β	Weight for Total earliness	$\beta \geq 0$	E_j	Earliness of job'j'
γ	Weight for makespan	$\gamma \geq 0$ $\alpha + \beta + \gamma = 1$		

Multicriteria objective function

Multicriteria decision making objective function proposed in this work has based on realistic environment for manufacturing system (i.e. minimizing weighted sum of total tardiness, total earliness and makespan).The significance of all the three objective function (Individual or combined) are explained below:-

S.No	Objective Function	Significance
(i)	Total Tardiness (T_j)	Total tardiness (T_j) is a due date related performance measure and it is considered as summation of tardiness of individual jobs. If maximum jobs are to be completed in time but few jobs left which is overdue as of improper scheduling than minimizing total tardiness reflects that situation so that all the jobs will be completed in time. Not meeting the due dates may cause loss of customer, market competitiveness and termed as tardiness penalty.
(ii)	Total Earliness (E_j)	Total earliness (E_j) is also a due date related performance measure but reflects early delivery of jobs and it is considered as summation of earliness of individual jobs. If the jobs are produced before the due dates, than it also creates problem of inventory for an organization or it may cause penalty to the industry in terms of inventory cost and termed as earliness penalty.
(iii)	Makespan (C_{max})	Makespan is also a performance criterion which is defined as completion time of last job to be manufactured. In scheduling it is very important as to utilize maximum resources and increase productivity. Minimization of makespan achieves the goal of an industry.
(iv)	Multicriteria (weighted sum of total tardiness, total earliness and makespan)	As minimization of all the three performance criteria are important for an industry in the dynamic environment of markets, upward stress of competition, earliness and tardiness penalty and overall for Just in Time (JIT) Manufacturing and increasing productivity. So, for achieving this, there is a requirement of scheduling system which considered multicritreia decision making. To congregate this, we have developed this multicriteria objective function, which may be very effective decision making tool for scheduling jobs in the dynamic environment.

Therefore, the formulation of multicriteria objective function is stated below:
Total weighted tardiness which reflects the due dates of jobs to be scheduled as considered for minimization of late deliverance of jobs and has defined as:

$$\sum_{j=1}^{n} T_j$$

$$\text{Where } T_j = C_j - d_j \qquad \text{if } C_j - d_j \geq 0$$

$$= 0 \qquad \text{otherwise}$$

Total earliness which reflects the early delivery of jobs to be scheduled as early delivery of jobs seems to be harmful and defined as:

$$\sum_{j=1}^{n} E_j$$

$$\text{Where } E_j = d_j - C_j \qquad \text{if } d_j - C_j \geq 0$$

$$= 0 \qquad \text{otherwise}$$

Another commonly performance measure is completion time of last job i.e makespan (C_{max}) which has been used for maximum utilization of resources to increase productivity.
Therefore in the present work, for the requirement of Just in Time (JIT) manufacturing in terms of earliness and tardiness and also for increasing productivity, we have proposed the multi criteria decision making objective function including all the above three performance measure i.e. weighted sum of total tardiness, total earliness and makespan simultaneously for flow shop scheduling with sequence dependent set up times and has been framed as:

$$Min\left[\alpha\sum_{j=1}^{n} T_j + \beta\sum_{j=1}^{n} E_j + \gamma C_{\max}\right]$$

3. HYBRID GENETIC ALGORITHM (HGA)

Genetic algorithm is the optimization technique which can be applied to various problems, including those that are NP-hard. The genetic algorithm does not ensured an optimal solution; however it usually provides good approximations in a reasonable amount of time as compared to exact algorithms. It uses probabilistic selection as a basis for evolving a population of problem solutions. An initial population is created and subsequent generations are created according to a pre-specified breeding and mutation methods inspired by nature.

A genetic algorithm must be initialized with a starting population. Generating of initial population may be varied: feasible only, randomized, using some heuristics etc. Simple genetic algorithm generates initial population randomly and limitation of that algorithm is that if the initial solution is better than solution provided by the algorithm may be of good quality and if it is inferior than final results may not be better in a reasonable time. As flow shop scheduling belongs to NP hard and there is large search space to be searched in flow shop scheduling for finding optimal solutions and hence it is probable that random generation of initial solutions provides relatively weak results. For this, initial feasible solution is obtained by some heuristics for judgement of optimality in a very reasonable time. Generation of initial sequence with some heuristics and than that sequence is used as the initial sequence along with population as the procedure of simple genetic algorithm and called as Hybrid Genetic Algorithm (HGA).

Outline of Hybrid Genetic Algorithm(HGA)

The Hybrid Genetic Algorithm (HGA) acts as globally search technique which is similar to simple genetic algorithm with only deviation of generation of initial solution. In HGA, initial feasible solution is generated with the help of some heuristics and than this initial sequence has been used along with the population according to population size for the executing the procedure of simple genetic algorithm. The proposed HGA is described as:-

Step 1: Initialization and evaluation

a) The algorithm begins with generation of initial sequence with special heuristics (SH) called as one of the chromosome of population as described in section 3.2.
b) Generation of (Ps-1) sequences randomly as per population size (Ps).
c) Combining of initial sequence obtained by special heuristics with randomly generated sequence to form number of sequences equal to population size (Ps).

Step2: Reproduction

The algorithm then creates a set of new populations. At each generation, the algorithm uses the individuals in the current generation to generate the next population. To generate the new population, the algorithm performs the following steps:

a) Scores each member of the current population by computing fitness (i.e. weighted sum of total tardiness, total earliness and makespan simultaneously).
b) Selects parents based on the fitness function (i.e. multicriteria decision making).
c) Some of the individuals in the current population that have best fitness are chosen as *elite* and these elite individuals are utilized in the next population.
d) Production of offspring from the parents by *crossover* from the pair of parents or by making random changes to a single parent (*mutation)*.
e) Replaces the current population with the children to form the next generation.

Step3: Stopping limit

The algorithm stops when time limit reaches to $n \times m \times 0.25$ seconds.

Proposed Special Heuristic(SH)

The Special Heuristic (SH), the procedure which is similar to NEH [19] has been developed to solve the multicriteria flow shop scheduling with due dates and sequence dependent set up times for instances upto 200 jobs and 20 machines developed by Taillord [19]. Procedure of SH is described as below:

Step 1. Generation of initial sequence.

Step2. Set k *= 2*. Pick the first two jobs from the initial sequence and schedule them in order to minimize the weighted sum of total tardiness, total earliness and makespan. As if there are only two jobs. Set the better one as the existing solution.

Step 3. Increment k by 1. Generate *k* candidate sequences by introducing the first job in the residual job list into each slot of the existing solution. Amongst these Candidates, select the better one with the least partial minimization of the weighted sum of total tardiness, total earliness and makespan simultaneously. Update the selected partial solution as the new existing solution.

*Step 4***.** If $k = n$, a feasible schedule has been found and stop. Otherwise, go to step 3.

Special heuristics SH1, SH2, SH3 and SH4 are obtained by using the EDD, LDD, EPDD and LPDD sequences respectively, in step 1 of proposed special heuristics. They have described below:

a) *Earliest Due Date (EDD):-* Schedule the jobs initially as per ascending order of due dates of jobs. (Kim, 1993).
b) *Latest Due Date (LDD):-* Arrange the jobs initially as per descending order of the due dates of jobs.

c) *Earliest processing time with due dates (EPDD):-* Schedule the jobs according to ascending order of $\left[\sum_{i=1}^{m} P_{ij} + d_j\right]$.

d) *Latest processing time with due dates (LPDD)*:- Arrange the jobs according to descending order of $\left[\sum_{i=1}^{m} P_{ij} + d_j\right]$.

Parameters Settings

- *Population Size (Ps):* Population size refers to the search space i.e. algorithm has to search the specified number of sequences and larger the sequence, more the time is needed to execute the process of genetic algorithm. As in flow shop scheduling number of possible sequences is equal to n!. Therefore, if the population size is equal to n! than application of genetic algorithm has no use. So, larger the initial population that is created, the more likely the best solution from it will be closer to optimal but at the cost of increased execution time. So, in the present work it is set to 50 irrespective the size of problem to solve in a reasonable time.
- *Crossover function:* Crossover is the breeding of two parents to produce a single child. That child has features from both parents and thus may be better or worse than either parent as per fitness function. Analogous to natural selection, the more fit the parent, the more likely the generation have. Different types of crossover have used in literature and after having experimental comparison , we have found that the order crossover(OX) provides the best results for the multicriteria problem considered among the partially matched crossover(PMX), Order crossover (OX), Cycle crossover (CX) and single point crossover (SPX). So, in the present work, we have applied the order crossover (OX).
- *Mutation function:* For each sequence in the parent population a random number is picked and by giving this sequence a percent chance of being mutated. If this sequence is picked for mutation then a copy of the sequence is made and operation sequence procedure reversed. Only operations from different jobs will be reversed so that the mutation will always produces a feasible schedule. From the experiment, it is found that reciprocal exchange (RX) proves to be good with combination of order crossover (OX) and hence been used.
- *Elite Count:* The best sequences found should be considered in subsequent generations. At a lowest, the only best solution from the parent generation needs to be imitating to the next generation thus ensuring the best score of the next generation is at least as better as the previous generation. Here elite is expressed as number of sequences. In this work, we have fixed the elite count as two means that we clone the top two sequences that have least fitness function for the next generation.
- *Crossover fraction:* It is the fraction for which crossover has to perform on the parents as per population size in each generation. This is fixed to 0.8 i.e crossover should be done on 80% of total population size.
- *Mutation Fraction:* It is also used as fraction and specified for which process of mutation has to perform on the parents as per population size in each generation. This is fixed to 0.15 i.e. Mutation should be done on 15% of total population size.
- *Stopping condition:* Stopping condition is used to terminate the algorithm for certain numbers of generation. In this work, for fair comparison among different SH based Hybrid Genetic algorithm, we have used time limit base stopping criteria. So, the algorithm stops when maximum time limit reaches $n \times m \times 0.25$ seconds.

4. RESULTS AND DISCUSSIONS

In this study, flow shop scheduling with sequence dependent set up time and due dates of jobs have been considered in flow shop environment. The multicriteria objective function including weighted sum of total tardiness, total earliness and makespan has been proposed which is very

effective decision making model for achieving industry as well as customer goals through scheduling the jobs. As the problems belong to NP hard, so we have also developed hybrid genetic algorithm, in which initial feasible sequence is obtained from special heuristic. In the present work, we have developed four special heuristics (SH) and hybrid with genetic algorithm and termed special heuristic based hybrid genetic algorithms HGA (SH1), HGA (SH2), HGA (SH3) and HGA (SH4) as stated in section 3.2. Problems upto 200 jobs and 20 machines developed by Taillord [20] in flow shop environment with sequence dependent set up time and due dates have been solved from the proposed hybrid genetic algorithm. Computational and experimental study for the entire four hybrid genetic algorithm has also been made for comparison. All experimental tests are conducted on a personal computer with P IV, core 2duo processor and 1 GB Ram. As proposed HGA generate initially only one sequence by SH and remaining as per population size (Ps) randomly, so for each size of problem, we have run HGA five times for taking final average to compensate randomness. Also for reasonable comparison, stopping limit of HGA has been fixed to time limit based criteria which is $n \times m \times 0.25$ seconds.
Comparison of all the four hybrid genetic algorithm has been done by calculating Error which is computed as:-

$$\text{Error (\%)} = \frac{Average_{sol} - Best_{sol}}{Best_{Sol}} X100$$

Where $Average_{sol}$ is the average solution obtained by a given algorithm and $Best_{sol}$ is the best solution obtained among all the methods or the best known solution. Lesser the error, better the results obtained. $Best_{sol}$ can be found from the results obtained by running HGA five times for a particular problem and Average solution is the final average solution produced by the algorithm for all the five runs. The Error for all the four HGA have been compared for five, ten and twenty machines problems with four sets of weights (0.33, 0.33, 0.33), (0.25,0.25,0.5) , (0.5, 0.25, 0.25) and (0.25, 0.25, 0.5) for multicriteria decision making objective function and have been shown in Figure 1, Figure 2 and Figure 3.

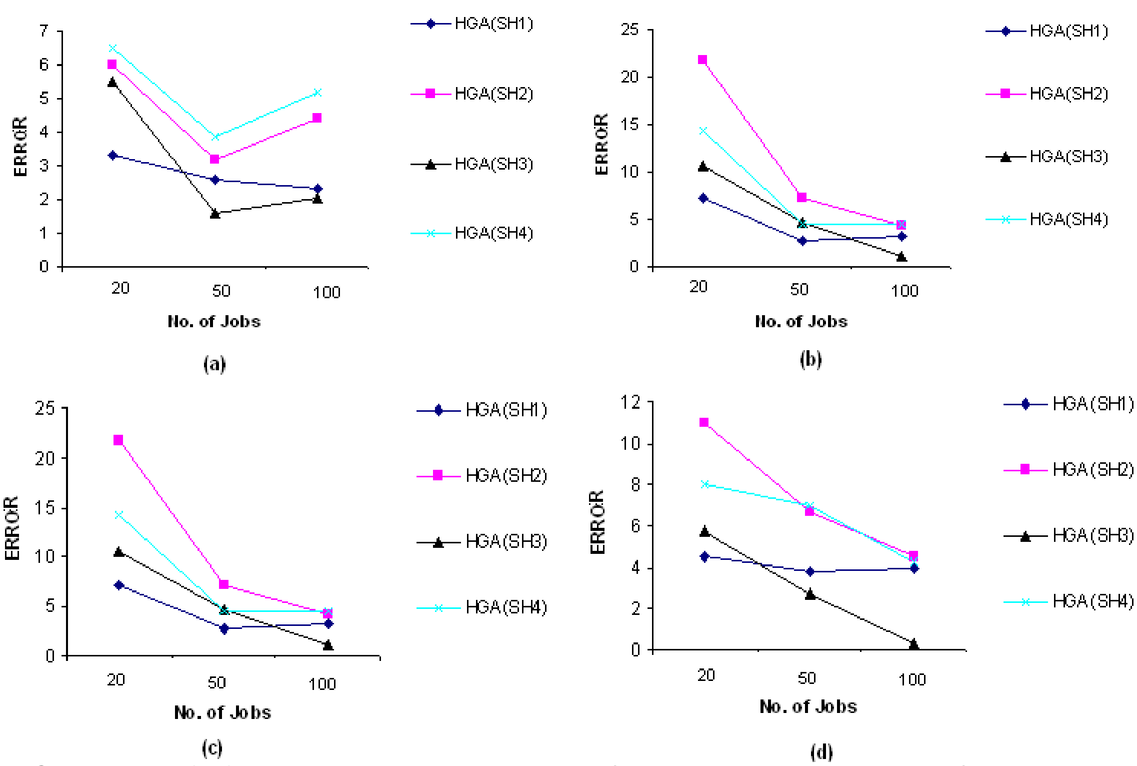

FIGURE1: Error for five machines problem **(a)** α = 0.33, β = 0.33 & γ = 0.33 **(b)** α = 0.25, β = 0.25 & γ = 0.5 **(c)** α = 0.5, β = 0.25 & γ = 0.25 **(d)** α = 0.25, β = 0.25 & γ = 0.5.

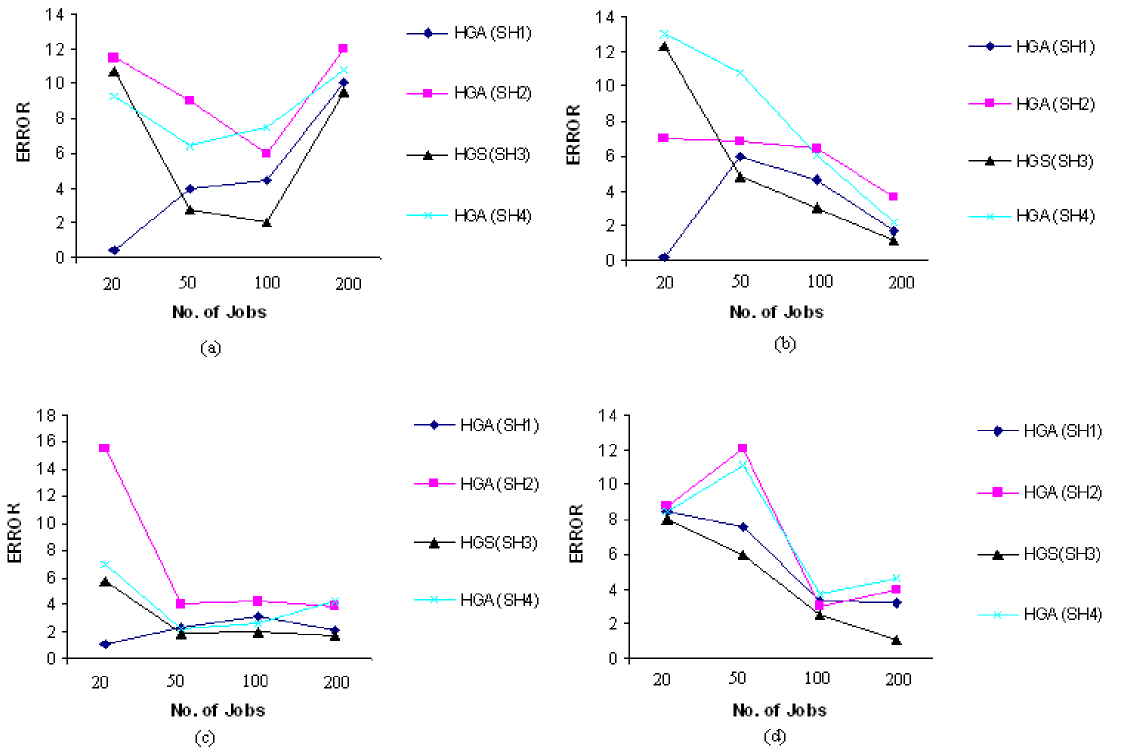

FIGURE 2: Error for ten machines problem **(a)** α = 0.33, β = 0.33 & γ = 0.33 **(b)** α = 0.25, β = 0.25 & γ = 0.5 **(c)** α = 0.5, β = 0.25 & γ = 0.25 (d) α = 0.25, β = 0.25 & γ = 0.5

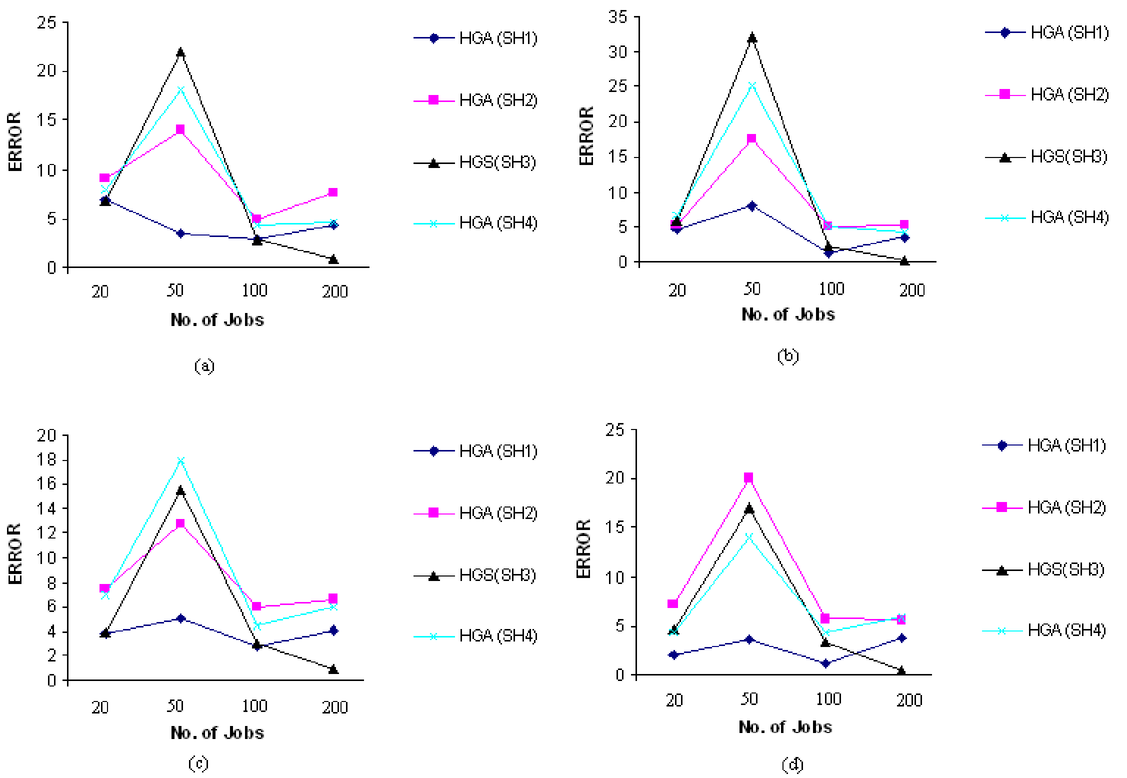

FIGURE 3: Error for twenty machines problem **(a)** α = 0.33, β = 0.33 & γ = 0.33 **(b)** α = 0.25, β = 0.25 & γ = 0.5 **(c)** α = 0.5, β = 0.25 & γ = 0.25 **(d)** α = 0.25, β = 0.25 & γ = 0.5

From the analysis for 5, 10 and 20 machines problems as shown in Figure 1, Figure 2 and Figure 3, performance of proposed SH1 based HGA upto 20 jobs and SH3 based HGA as the jobs size increases, showed superiority over others for all the four sets of weight values ((0.33, 0.33, 0.33), (0.25,0.25,0.5) , (0.5, 0.25, 0.25) and (0.25, 0.25, 0.5)) for multicriteria decision making in flow shop scheduling under sequence dependent set up time i.e. weighted sum of total tardiness, total earliness and makespan.

5. CONCLUSIONS

In the present work, we have framed multicriteria decision making for flow shop scheduling with weighted sum of total tardiness, total earliness and makespan under sequence dependent set up time and also proposed four special heuristic based hybrid genetic algorithms. Computational analysis has also been done for comparing the performance of proposed four HGA's i.e. HGA (SH1), HGA (SH2), HGA (SH3) and HGA (SH4). The HGA's have been tested upto 200 jobs and 20 machines problems in flow shop scheduling as derived by Taillord [20] for all the four weight values (α, β and γ) for fitness function (i.e. (0.33, 0.33, 0.33), (0.25, 0.25, 0.5), (0.5, 0.25, 0.25) and (0.25, 0.25, 0.5)). From the analysis it has been concluded that the proposed HGA(SH1) for smaller and HGA(SH3) for larger job size problems showed superiority over other for 5,10 and 20 machines problem for multicriteria decision making flow shop scheduling (i.e. weighted sum of total tardiness, total earliness and makespan) under sequence dependent set up time and due dates.

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