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MULTI HYBRIDIZATION OF SWARM INTELLIGENCE METHODS TO SOLVE JOB SHOP SCHEDULING PROBLEM

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ABSTRACT

Scheduling is one of the fundamental and crucial elements in making production organizations efficient and effective in the usage of resources. It also concerns the allocation of resources over a period of time to execute a set of jobs. The purpose of paper is to establish multi hybridization of swarm intelligence methods HABCPSOGA to solve job shop scheduling problems. The performance of proposed algorithms are evaluated by applying it to all well-known benchmark instances and by comparing theirs results with the results of others methods HABCGA available in the literature. The experiment results show that the multi hybridization of swarm intelligence methods improve the effectiveness of the algorithm and they indicate how these proposed methods influence the resolution of the defined problem.

Keywords: *Scheduling, Job Shop, Multi Hybridization, Swarm Intelligence, GA.*

1. INTRODUCTION

Production scheduling is a process of arranging, controlling and optimizing work and workloads with the purpose of performing some tasks and satisfying some criteria [1, 2].

Job shop scheduling is the essential subject for manufacturing systems due to its NP-hard kind. The core problem in job shop scheduling is to optimize the utilization of machines to obtain the shortest time in completing the activities. Therefore, many different metaheuristics are developed for this problem. These metaheuristics do not ensure converging to globally best solutions but provide high quality or near optimal solutions in a short time. Amongst the metaheuristics approaches, hybrid and adaptive techniques provide very good solutions.

The efficiency of population based metaheuristic depends on two components: Exploration and exploitation [3].

The exploration is required to guarantee that every section of the space is searched enough to furnish a reliable estimate of the global optimum. However, exploitation is significant since the elaboration of the current solution will often generate a better solution. The inconvenience of exploration is waste of many computational efforts because a large number of new solutions can be far from global optimality. However, the inconvenience of exploitation is that can get stuck in a local optimum because the final solution point depends on the starting point.

The hybrid strategies have been constructed to improve the speed of convergence of the metaheuristic and to improve the quality of the solutions obtained by the metaheuristic. Any types of algorithms could be hybridized [4]. There are three hybridization classifications:

1. Sequential hybridization consists of applying a variety of methods, the solution of the first method is an initialization of the next method.
2. Synchronous parallel hybridization consists of including a method in an operator of another method.
3. Asynchronous parallel hybridization, the hybrid methods share data throughout the search process.

In the literature, authors frequently considered basic hypothesis while solving job shop scheduling problem [5]:

- **a.** Job can't visit one machine more than once.
- **b.** There are no precedence constraints on operations of different jobs.
- **c.** Machine can process only one job at current time.
- **d.** No specifications of release and due dates.
- **e.** No preemptions of operations.

The objective is to minimize the makespan, which is the total time for all jobs accomplished.

In the last few years, researchers has extended towards flexible job shop scheduling problems in which more than one machine for performing each operation are considered. It present more complexity.

The methods proposed to solve the JSSP are categorized into two types: Exact methods and approximation methods. The exact method purpose to find an optimal solution, and they consume a high amount of time as they explore the solution space, as consequence their use has been limited for small real-life problems. The approximation method, as the name indicates, do not guarantee an optimal solution, they do provide an approximate but useful solution in a reasonable time.

For several years great effort has been dedicated to solve the Job shop scheduling problem, in fact many researchers have proposed various methods: Simulated annealing [6-8], genetic algorithm [9-13], search tabu [14-18], ant colony optimization [19, 20], neural network [21] shifting bottleneck procedure [22, 23], guided local search [24] , GRASP [25] and propagation of constraints [26, 27], invasive weed optimization [28], guided ejection local searches [29], genetic programming [30] , multi-modal immune algorithms [31], immune system [32], particle swarm optimization [33-36], harmony search [37], imperialist competitive algorithm [38] , parallel genetic algorithm and neural network [39], beam search [40], One of the popular solution models considered by many researchers has been a hybrid methods such as hybrid genetic algorithm and tabu search [41], hybrid genetic algorithm with a random key representation [42], hybrid methods combining various heuristic techniques [43-46], hybrid GA [47-50], hybrid swarm intelligence algorithm based on particle swarm optimization [33]. The summary of some contributions to solve job shop scheduling problem has been presented in [51].

However, to the authors' knowledge, very few publications are available in the literature that studied multi hybridization of swarm intelligence methods and that made an in-depth analysis for verifying how the multi hybridization of swarm intelligence methods influence the resolution of job shop scheduling problems.

The rest of the paper is structured into three sections: The material and method are described in section 2. In section 3, the authors presented the results and discussion. The conclusion is reported in section 4.

2. THE MATERIAL AND METHOD

2.1. Fundamentals of Particle Swarm Optimization

Particle swarm optimization (PSO) is a swarm-based optimization technique inspired by nature and was presented by [52]. The algorithm is inspired by the collecting and teaching patterns of birds and fish. It is an adaptive algorithm based on a social-psychological metaphor; a population of individuals changes by returning stochastically toward antecedent successful zones. The particularity of this technique is represented by the transmission and sharing of information [53].

The procedure of PSO is as follows:

1. Initialize randomly a population of n particles.
2. Calculate fitness value for each particle, if the fitness value is better than the best fitness value pbest .
3. Set current value as the new pbest.
4. Choose particle with the best fitness value of all the particles as the gbest.
   For each particle, calculate particle position and velocity according to the equation [54]:

   V [k+1] = μ*V [k] +C1*rand()*(pbest[k]-current[k])+ C2*rand()*(gbest[k]-current[k])

   Where current [k+1] = current[k] +V[k], V [] is the particle velocity, current [] is the current solution, rand () is random functions in the range [0, 1]. μ is the inertia factor and used to control intensification and diversification. C1 and C2 are the apprenticeship factors, C1 + C2 = 1.
5. Particle velocities on each dimension are fixed to a maximum velocity V_{max}. If the sum of acceleration would cause the velocity on that dimension to exceed V_{max} specified by user, the velocity on the dimension is limited to V_{max}.
6. Terminate if maximum of iterations is reached. Else, goto 2.

PSO has better capacity of global questing and it has been successfully implemented to many areas and it has a poor local search and has a slow convergence rate in refined search strategy.

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2.2. Fundamentals of Artificial Bee Colony Algorithm

Artificial bee colony algorithm ABC is a swarm-based metaheuristic algorithm, developed by [55] for numerical problems optimization. The algorithm is interested by the intelligent behavior of honeybees, that is, foraging behavior of honeybee colonies. The artificial bee colony algorithm is constituted by four steps: initialization step, employed bees step, onlooker bees step and scout bees step.

The basic artificial bee colony steps are as follows:

1. Sent the employed bees to the food sources and measure their nectar amounts, randomly.
2. If an employed bee discovers a better solution, update the memory of employed bee.
3. Then, counts the number of the searches around the source in the memory of employed bee.
4. Share the nectar and position information of the food sources with the onlooker bees if all employed bees complete the search operation.
5. Evaluate all the information from employed bees by the onlooker bee and choose a probably profitable food source.
6. Search the neighborhood of the source by the onlooker bee after arriving at the selected area and update the food source position just as an employed bee does if the onlooker bee discovers a better solution. The criterion for determination of a new food source is founded on the visually comparison process of food source positions.
7. Stop the intensification process of the sources abandoned by the employed/onlooker bees if the new solution cannot be further improved through a predetermined number of trials limit. At this moment, the employed/onlooker bees become scout bees.
8. Send the scouts into the search area for discovering new food sources, randomly.
9. Remember the best food source found so far.
10. Repeat these steps until a termination criterion is satisfied.

The stopping criterion of the artificial bee colony defines the maximum number of cycles that a food source can keep without improving before being replaced.

2.3. Fundamentals of Genetic Algorithm

Genetic algorithm is one of the popular metaheuristics, developed by [56]. The motivation of GA is to promote the survival and reproduction of the best-adapted individuals to the environment.

The element and mechanism of genetic algorithm are representation, population, evaluation, selection, operators and parameter.

The procedure of GA is as follows:

1. Initialize randomly the population of individual.
2. Evaluate the fitness function of each individual
3. Repeat the following phases until the termination criteria are satisfied:
   i. Select the best appropriate individuals for reproduction.
   ii. Perform genetic operations, crossover and mutation to generate new offspring.
   iii. Evaluate the individual fitness of new members.
   iv. Replace the least appropriate individuals with new individuals.
4. Report the best solution of the appropriate individual.

The crossover operator and the mutation operator represents the core operators in GA.

The crossover operator is selected in such a way that the formed offspring's have more probabilities of survival than the parents.

In the literature, several crossover operators have been applied in job shop scheduling such as partially-mapped crossover (PMX), order crossover (OX), linear order crossover (LOX), cycle crossover (CX), order-based crossover (OBX), position-based crossover (PBX), job based order crossover (JOX), subsequence-exchange operator (SSX), uniform crossover (UOX), extrapolation-directed (EDX), partial schedule exchange crossover, extended precedence preservative crossover (EPPX). However, this study take into account only four crossover operators: PMX [57], PBX [58], PPX [59] and OX [60].

The mutation operator has two objectives, the first one is to ameliorate the random local search ability of algorithm and the second one is to preserve the diversity of the individuals in the population. In the literature, different mutation operators have been recommended such as swap [61], inversion [62], insertion [63] and displacement mutation [64].

2.4. The proposed Methods

The artificial bee colony ABC has good capacity to search for the global optimum, but it is not directly used, because the artificial bee colony stores it at each iteration, however the particle swarm optimization can directly use the global optimum at iteration.

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Generating a new food source in ABC by using crossover, mutation operations in the ABC specific phases explore the search space and search for new area of solution. When mutation is achieved, there is an opportunity of changing the local best position and the algorithm may not be trapped into local optima. During the life cycle of ABC optimization technique, the mutation phase is effectuated on the probabilistic way in each food searching operation for each iteration.

In order to surmount the weakness existing in these algorithms, the proposed multi synchronous parallel hybridization is applied.

The authors established a new technique of multi hybridization (multi synchronous parallel hybridization) of ABC, PSO and GA denoted as HABCPSOGA, this technique consist to use in the employed bees phase or/and in the onlooker bees phase or/and in the scout bees phase, the crossover and the mutation operator, or the position and the velocity updating process. This is illustrated in Table 2.

Therefore, the hybridization of ABC, GA and PSO is according to the configurations given in Table 3.

Table 3: The Configurations Of Hybridization Of ABC, PSO and GA .

Configuration	Crossover	Mutation
Configuration 1	PMX	Inversion
Configuration 2	OX	Inversion
Configuration 3	PPX	Inversion
Configuration 4	PBX	Inversion
Configuration 5	PMX	Insertion
Configuration 6	OX	Insertion
Configuration 7	PPX	Insertion
Configuration 8	PBX	Insertion
Configuration 9	PMX	Swap
Configuration 10	OX	Swap
Configuration 11	PPX	Swap
Configuration 12	PBX	Swap
Configuration 13	PMX	Displacement
Configuration 14	OX	Displacement
Configuration 15	PPX	Displacement
Configuration 16	PBX	Displacement

Table 2: The Structure Of Hybrid ABC, PSO And GA.

	ABC		
HABCPSOGA	Employed bee phase	Onlooker bee phase	Scout bee phase
HABCPSOGA1		crossover, mutation operations	position and velocity updation process
HABCPSOGA2	crossover, mutation operations	crossover, mutation operations	position and velocity updation process
HABCPSOGA3	crossover, mutation operations		position and velocity updation process
HABCPSOGA4	crossover, mutation operations	position and velocity updation process	
HABCPSOGA5		position and velocity updation process	crossover, mutation operations
HABCPSOGA6	crossover, mutation operations	position and velocity updation process	crossover, mutation operations
HABCPSOGA7	position and velocity updation process	crossover, mutation operations	
HABCPSOGA8	position and velocity updation process		crossover, mutation operations
HABCPSOGA9	position and velocity updation process	crossover, mutation operations	crossover, mutation operations

Consequently, the procedure of HABCPSOGA3 can be found in Figure 1.

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Initialize input parameters.
Initialize the number of food sources.
Initialize the number of onlooker bees.
Initialize the number of scout bees.
Initialize populations by generating random food sources.
Calculate the fitness value of each food source.
Determine the best food resource.

For every employed bee
    Generate a new food source by using the crossover, mutation operations.
    Calculate fitness value for every newly generated food source.
    Compute the best food source.

For every onlooker bee
    Generate a new food source randomly.
    Calculate fitness value for every newly generated food source.
    Compute the best food source.

For every Scout bee,
Generate a new food source by using the the position and velocity updation process.
Calculate fitness value for every newly generated food source
Compute the best food source.
Compare the scout bee's best food source, the employed bee's best food source and the onlooker bee's best food source using their fitness values.
Among these food sources, Store the best food source is stored in the scout bee's phase and remain food sources to the next iteration.
The process is repeated until the stopping criterion is met.
The best food source is obtained with its objective value from the scout bee's phase.

Figure 1: The Procedure Of HABCPSOGA3 Method.

3. RESULTS AND DISCUSSION

The proposed hybrid techniques were programmed in Eclipse. The PC configuration is as follows: Processor: Intel Core i7, OS: Windows 8.1, CPU speed: 2.10 GHz, RAM: 6 GB. There were tested on 250 Benchmark instances from the classical OR-library. The Benchmark instances are as follows : FT instances [65], LA instances [66], ORB instances [67], SWV instances [68], ABZ instances [69], YN instances [70], TA instances [71], DMU instances [72], CAR instances [73].

The obtained results are compared with other best-known solutions obtained by using others techniques and compared with the results of methods HABCGA available in the literature[51].

The overall results of proposed methods are summarized in Table 4.

The analysis and simulation indicate that only the proposed methods HABCPSOGA2, HABCPSOGA6 and HABCPSOGA9 in all configurations are given 100% results equal to the best-known solution in all benchmark instances FT (3), LA (40), ORB (10), SWV (20), ABZ (5), YN (4), TA (80), DMU (80) and CAR (8), this is illustrated in Figure 2. Regardless the crossover operator type and mutation operator type and regardless if these methods are employed in its employed bees phase, onlooker bees phase and scout bees phase, crossover operator and mutation operator, or position and velocity updating process, the proposed methods are given result 100% equal to the best-known solution in all benchmark instances.

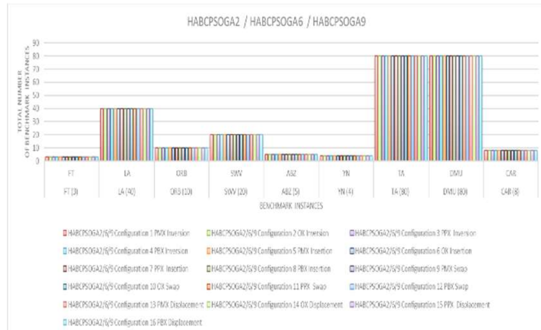

Figure 2: The Obtained Result Of The Proposed Methods HABCPSOGA2, HABCPSOGA6 And HABCPSOGA9 In All Configurations.

It has been found that all proposed methods in all configurations are produced 100% results equal to the best-known solution in FT (3), ORB (10), SWV (20), ABZ (5), YN (4) and CAR (8) instances as shown in Figure 3. These methods are given the best results independent of hybridization type, crossover operator type and mutation operator type in FT (3), ORB (10), SWV (20), ABZ (5), YN (4) and CAR (8) instances.

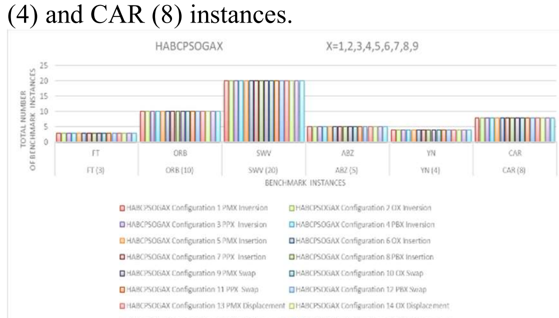

Figure 3: The Obtained Results Of All Proposed Methods In All Configurations To Solve FT (3), ORB (10), SWV (20), ABZ (5), YN (4) and CAR (8) Instances.

The results show that all proposed methods in all configurations except HABCPSOGA7 and HABCPSOGA8 are produced 100% results equal to the best-known solution in LA (40) instances as shown in Figure 4. Whatever the crossover operator and the mutation and the hybridization kind, these methods are given result 100% equal to the best-known solution in LA (40) instances.

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Table 4: The Obtained Results Of Hybridization Of ABC, PSO And GA In All Configurations.

			Benchmark Instances	FT (3)		LA (40)		ORB (10)		SWV (20)		ABZ (5)		YN (4)		TA (80)		DMU (80)		CAR (8)		Total Number of Benchmark	
				FT		LA		ORB		SWV		ABZ		YN		TA		DMU		CAR			
Hybrid ABC PSO GA	Configuration	Crossover	Mutation	3		40		10		20		5		4		80		80		8		250	
HABCPSOGA1	Configuration 1	PMX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	72	90%	80	100%	8	100%	242	97%
HABCPSOGA1	Configuration 2	OX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	79	99%	8	100%	249	100%
HABCPSOGA1	Configuration 3	PPX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	71	89%	80	100%	8	100%	241	96%
HABCPSOGA1	Configuration 4	PBX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	78	98%	8	100%	248	99%
HABCPSOGA1	Configuration 5	PMX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	75	94%	80	100%	8	100%	245	98%
HABCPSOGA1	Configuration 6	OX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	79	99%	8	100%	249	100%
HABCPSOGA1	Configuration 7	PPX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	70	88%	80	100%	8	100%	240	96%
HABCPSOGA1	Configuration 8	PBX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	76	95%	8	100%	246	98%
HABCPSOGA1	Configuration 9	PMX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	73	91%	80	100%	8	100%	243	97%
HABCPSOGA1	Configuration 10	OX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	76	95%	75	94%	8	100%	241	96%
HABCPSOGA1	Configuration 11	PPX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	75	94%	80	100%	8	100%	245	98%
HABCPSOGA1	Configuration 12	PBX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	78	98%	77	96%	8	100%	245	98%
HABCPSOGA1	Configuration 13	PMX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	78	98%	80	100%	8	100%	248	99%
HABCPSOGA1	Configuration 14	OX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	77	96%	78	98%	8	100%	245	98%
HABCPSOGA1	Configuration 15	PPX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	71	89%	80	100%	8	100%	241	96%
HABCPSOGA1	Configuration 16	PBX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	79	99%	79	99%	8	100%	248	99%
HABCPSOGA2	Configuration 1	PMX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA2	Configuration 2	OX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA2	Configuration 3	PPX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA2	Configuration 4	PBX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA2	Configuration 5	PMX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA2	Configuration 6	OX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA2	Configuration 7	PPX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%

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HABCPSOGA2	Configuration 8	PBX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA2	Configuration 9	PMX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA2	Configuration 10	OX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA2	Configuration 11	PPX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA2	Configuration 12	PBX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA2	Configuration 13	PMX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA2	Configuration 14	OX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA2	Configuration 15	PPX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA2	Configuration 16	PBX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA3	Configuration 1	PMX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA3	Configuration 2	OX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	76	95%	8	100%	246	98%
HABCPSOGA3	Configuration 3	PPX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA3	Configuration 4	PBX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	78	98%	8	100%	248	99%
HABCPSOGA3	Configuration 5	PMX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA3	Configuration 6	OX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	79	99%	8	100%	249	100%
HABCPSOGA3	Configuration 7	PPX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA3	Configuration 8	PBX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	76	95%	8	100%	246	98%
HABCPSOGA3	Configuration 9	PMX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA3	Configuration 10	OX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	77	96%	78	98%	8	100%	245	98%
HABCPSOGA3	Configuration 11	PPX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA3	Configuration 12	PBX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	76	95%	76	95%	8	100%	242	97%
HABCPSOGA3	Configuration 13	PMX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA3	Configuration 14	OX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	78	98%	78	98%	8	100%	246	98%
HABCPSOGA3	Configuration 15	PPX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA3	Configuration 16	PBX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	77	96%	79	99%	8	100%	246	98%
HABCPSOGA4	Configuration 1	PMX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	72	90%	80	100%	8	100%	242	97%
HABCPSOGA4	Configuration 2	OX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	79	99%	8	100%	249	100%
HABCPSOGA4	Configuration 3	PPX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	71	89%	80	100%	8	100%	241	96%
HABCPSOGA4	Configuration 4	PBX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	78	98%	8	100%	248	99%
HABCPSOGA4	Configuration 5	PMX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	70	88%	80	100%	8	100%	240	96%
HABCPSOGA4	Configuration 6	OX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	75	94%	76	95%	8	100%	241	96%

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

HABCPSOGA4	Configuration 7	PPX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	70	88%	80	100%	8	100%	240	96%
HABCPSOGA4	Configuration 8	PBX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	76	95%	77	96%	8	100%	243	97%
HABCPSOGA4	Configuration 9	PMX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	71	89%	80	100%	8	100%	241	96%
HABCPSOGA4	Configuration 10	OX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	79	99%	79	99%	8	100%	248	99%
HABCPSOGA4	Configuration 11	PPX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	75	94%	80	100%	8	100%	245	98%
HABCPSOGA4	Configuration 12	PBX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	76	95%	78	98%	8	100%	244	98%
HABCPSOGA4	Configuration 13	PMX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	73	91%	80	100%	8	100%	243	97%
HABCPSOGA4	Configuration 14	OX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	76	95%	8	100%	246	98%
HABCPSOGA4	Configuration 15	PPX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	71	89%	80	100%	8	100%	241	96%
HABCPSOGA4	Configuration 16	PBX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	78	98%	8	100%	248	99%
HABCPSOGA5	Configuration 1	PMX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	74	93%	80	100%	8	100%	244	98%
HABCPSOGA5	Configuration 2	OX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	76	95%	8	100%	246	98%
HABCPSOGA5	Configuration 3	PPX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	70	88%	80	100%	8	100%	240	96%
HABCPSOGA5	Configuration 4	PBX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	79	99%	8	100%	249	100%
HABCPSOGA5	Configuration 5	PMX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	75	94%	80	100%	8	100%	245	98%
HABCPSOGA5	Configuration 6	OX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	77	96%	77	96%	8	100%	244	98%
HABCPSOGA5	Configuration 7	PPX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	71	89%	80	100%	8	100%	241	96%
HABCPSOGA5	Configuration 8	PBX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	78	98%	78	98%	8	100%	246	98%
HABCPSOGA5	Configuration 9	PMX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	75	94%	80	100%	8	100%	245	98%
HABCPSOGA5	Configuration 10	OX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	77	96%	79	99%	8	100%	246	98%
HABCPSOGA5	Configuration 11	PPX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	72	90%	80	100%	8	100%	242	97%
HABCPSOGA5	Configuration 12	PBX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	77	96%	78	98%	8	100%	245	98%
HABCPSOGA5	Configuration 13	PMX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	74	93%	80	100%	8	100%	244	98%
HABCPSOGA5	Configuration 14	OX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	78	98%	8	100%	248	99%
HABCPSOGA5	Configuration 15	PPX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	70	88%	80	100%	8	100%	240	96%
HABCPSOGA5	Configuration 16	PBX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	79	99%	8	100%	249	100%
HABCPSOGA6	Configuration 1	PMX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA6	Configuration 2	OX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA6	Configuration 3	PPX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA6	Configuration 4	PBX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA6	Configuration 5	PMX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

HABCPSOGA6	Configuration 6	OX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA6	Configuration 7	PPX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA6	Configuration 8	PBX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA6	Configuration 9	PMX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA6	Configuration 10	OX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA6	Configuration 11	PPX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA6	Configuration 12	PBX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA6	Configuration 13	PMX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA6	Configuration 14	OX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA6	Configuration 15	PPX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA6	Configuration 16	PBX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA7	Configuration 1	PMX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA7	Configuration 2	OX	Inversion	3	100%	39	98%	10	100%	20	100%	5	100%	4	100%	79	99%	75	94%	8	100%	243	97%
HABCPSOGA7	Configuration 3	PPX	Inversion	3	100%	37	93%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	247	99%
HABCPSOGA7	Configuration 4	PBX	Inversion	3	100%	39	98%	10	100%	20	100%	5	100%	4	100%	76	95%	75	94%	8	100%	240	96%
HABCPSOGA7	Configuration 5	PMX	Insertion	3	100%	34	85%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	244	98%
HABCPSOGA7	Configuration 6	OX	Insertion	3	100%	38	95%	10	100%	20	100%	5	100%	4	100%	78	98%	78	98%	8	100%	244	98%
HABCPSOGA7	Configuration 7	PPX	Insertion	3	100%	36	90%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	246	98%
HABCPSOGA7	Configuration 8	PBX	Insertion	3	100%	38	95%	10	100%	20	100%	5	100%	4	100%	79	99%	79	99%	8	100%	246	98%
HABCPSOGA7	Configuration 9	PMX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA7	Configuration 10	OX	Swap	3	100%	39	98%	10	100%	20	100%	5	100%	4	100%	80	100%	75	94%	8	100%	244	98%
HABCPSOGA7	Configuration 11	PPX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA7	Configuration 12	PBX	Swap	3	100%	38	95%	10	100%	20	100%	5	100%	4	100%	80	100%	78	98%	8	100%	246	98%
HABCPSOGA7	Configuration 13	PMX	Displacement	3	100%	38	95%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	248	99%
HABCPSOGA7	Configuration 14	OX	Displacement	3	100%	39	98%	10	100%	20	100%	5	100%	4	100%	80	100%	76	95%	8	100%	245	98%
HABCPSOGA7	Configuration 15	PPX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA7	Configuration 16	PBX	Displacement	3	100%	39	98%	10	100%	20	100%	5	100%	4	100%	80	100%	77	96%	8	100%	246	98%
HABCPSOGA8	Configuration 1	PMX	Inversion	3	100%	33	83%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	243	97%
HABCPSOGA8	Configuration 2	OX	Inversion	3	100%	38	95%	10	100%	20	100%	5	100%	4	100%	77	96%	78	98%	8	100%	243	97%
HABCPSOGA8	Configuration 3	PPX	Inversion	3	100%	38	95%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	248	99%
HABCPSOGA8	Configuration 4	PBX	Inversion	3	100%	39	98%	10	100%	20	100%	5	100%	4	100%	76	95%	79	99%	8	100%	244	98%

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

HABCPSOGA8	Configuration 5	PMX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA8	Configuration 6	OX	Insertion	3	100%	38	95%	10	100%	20	100%	5	100%	4	100%	76	95%	78	98%	8	100%	242	97%
HABCPSOGA8	Configuration 7	PPX	Insertion	3	100%	37	93%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	247	99%
HABCPSOGA8	Configuration 8	PBX	Insertion	3	100%	39	98%	10	100%	20	100%	5	100%	4	100%	78	98%	78	98%	8	100%	245	98%
HABCPSOGA8	Configuration 9	PMX	Swap	3	100%	39	98%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	249	100%
HABCPSOGA8	Configuration 10	OX	Swap	3	100%	37	93%	10	100%	20	100%	5	100%	4	100%	80	100%	76	95%	8	100%	243	97%
HABCPSOGA8	Configuration 11	PPX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA8	Configuration 12	PBX	Swap	3	100%	37	93%	10	100%	20	100%	5	100%	4	100%	80	100%	75	94%	8	100%	242	97%
HABCPSOGA8	Configuration 13	PMX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA8	Configuration 14	OX	Displacement	3	100%	39	98%	10	100%	20	100%	5	100%	4	100%	80	100%	75	94%	8	100%	244	98%
HABCPSOGA8	Configuration 15	PPX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA8	Configuration 16	PBX	Displacement	3	100%	37	93%	10	100%	20	100%	5	100%	4	100%	80	100%	79	99%	8	100%	246	98%
HABCPSOGA9	Configuration 1	PMX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA9	Configuration 2	OX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA9	Configuration 3	PPX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA9	Configuration 4	PBX	Inversion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA9	Configuration 5	PMX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA9	Configuration 6	OX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA9	Configuration 7	PPX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA9	Configuration 8	PBX	Insertion	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA9	Configuration 9	PMX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA9	Configuration 10	OX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA9	Configuration 11	PPX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA9	Configuration 12	PBX	Swap	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA9	Configuration 13	PMX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA9	Configuration 14	OX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA9	Configuration 15	PPX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%
HABCPSOGA9	Configuration 16	PBX	Displacement	3	100%	40	100%	10	100%	20	100%	5	100%	4	100%	80	100%	80	100%	8	100%	250	100%

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

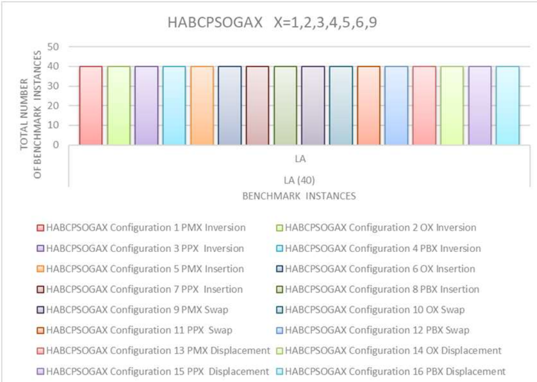

Figure 4: The Obtained Results Of The Proposed Methods except HABCPSOGA7 and HABCPSOGA8 In All Configurations To Solve LA (40) Instances.

The results show that the proposed methods HABCPSOGA7 in configuration 1, configuration 9, configuration 11 and configuration 15 (that used PMX with inversion mutation or swap mutation and that used PPX with swap mutation or displacement mutation), are given 100% results equal to the best-known solution in LA (40) instances as shown in Figure 5.

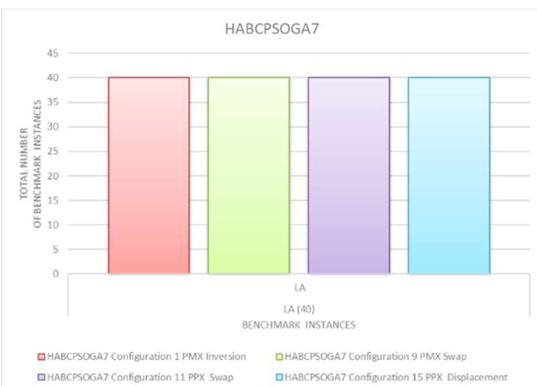

Figure 5: The Obtained Results Of HABCPSOGA7 In Configuration 1, Configuration 9, Configuration 11, Configuration 15 To Solve LA (40) Instances.

As follows from Figure 5:

- ✓ The proposed method HABCPSOGA7 that used PMX with inversion mutation or swap mutation and the HABCPSOGA7 that used PPX with swap mutation or displacement mutation are produced better results than the HABCPSOGA7 that used PMX with insertion mutation or displacement mutation.
- ✓ The proposed method HABCPSOGA7 that used PMX with inversion mutation or swap mutation and the HABCPSOGA7 that used PPX with swap mutation or displacement mutation are produced better results than the HABCPSOGA7 that used PPX with insertion mutation or inversion mutation.
- ✓ The proposed method HABCPSOGA7 that used PMX with inversion mutation or swap mutation and the HABCPSOGA7 that used PPX with swap mutation or displacement mutation are produced better results than the HABCPSOGA7 that used OX with others mutation operators.
- ✓ The proposed method HABCPSOGA7 that used PMX with inversion mutation or swap mutation and the HABCPSOGA7 that used PPX with swap mutation or displacement mutation are produced better results than the HABCPSOGA7 that used PBX with others mutation operators.

The results show that the proposed methods HABCPSOGA8 in configuration 5, configuration 11, configuration 13 and configuration 15 (that used PMX with insertion mutation or displacement mutation and that used PPX with swap mutation or displacement mutation) are given 100% results equal to the best known solution in LA (40) instances as shown in Figure 6.

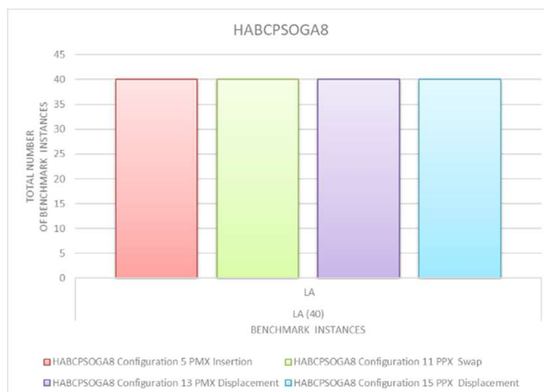

Figure 6: The Obtained Results Of HABCPSOGA8 In Configuration 5, Configuration 11, Configuration 13 And Configuration 15 To Solve LA (40) Instances.

As follows from the Figure 6:

- ✓ The proposed method HABCPSOGA8 that used PMX with insertion mutation or displacement mutation and the HABCPSOGA8 that used PPX with swap mutation or displacement mutation are produced better results than the HABCPSOGA8 that used PMX with swap mutation or inversion mutation.
- ✓ The proposed method HABCPSOGA8 that used PMX with insertion mutation or displacement mutation and the HABCPSOGA8 that used PPX with swap mutation or displacement mutation are produced better results than the HABCPSOGA8 that used PPX with insertion

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

mutation or inversion mutation.

- ✓ The proposed method HABCPSOGA8 that used PMX with insertion mutation or displacement mutation and the HABCPSOGA8 that used the PPX with swap mutation or displacement mutation are produced better results than the HABCPSOGA8 that used OX with others mutation operators.
- ✓ The proposed method HABCPSOGA8 that used PMX with insertion mutation or displacement mutation and the HABCPSOGA8 that used PPX with swap mutation or displacement mutation are produced better results than the HABCPSOGA8 that used PBX with others mutation operators.

The results show that the proposed methods HABCPSOGA1 in configuration 2, configuration 4, configuration 6 and configuration 8 (that used OX with inversion mutation or insertion mutation and that used PBX with inversion mutation or insertion mutation) are given 100% results equal to the best known solution in TA (80) instances as shown in Figure 7.

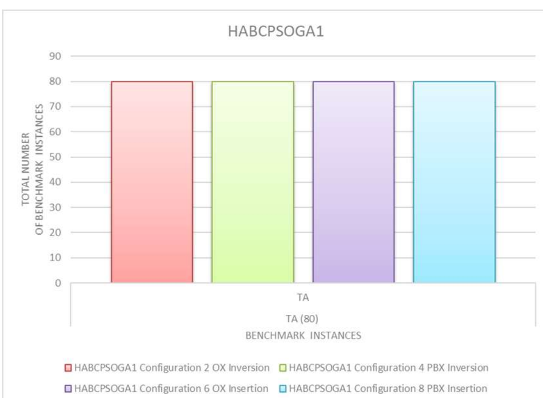

Figure 7: The Obtained Results Of HABCPSOGA1 In Configuration 2, Configuration 4, Configuration 6 And Configuration 8 To Solve TA (80) Instances.

As follows from the Figure 7:

- ✓ The proposed method HABCPSOGA1 that used OX with insertion mutation or inversion mutation and the HABCPSOGA1 that used PBX with insertion mutation or inversion mutation are produced better results than the HABCPSOGA1 that used PPX with others mutation operators or the HABCPSOGA1 that used MPX with others mutation operators.
- ✓ The proposed method HABCPSOGA1 that used OX with insertion mutation or inversion mutation and the HABCPSOGA1 that used PBX with insertion mutation or inversion mutation are produced better results than the HABCPSOGA1 that used OX with others mutation operators or the HABCPSOGA1 that used PBX with others mutation operators.

The results show that the proposed methods HABCPSOGA3 in all configurations except in configuration 10, configuration 12 and configuration 14 are given 100% results equal to the best known solution in TA (80) instances as shown in Figure 8.

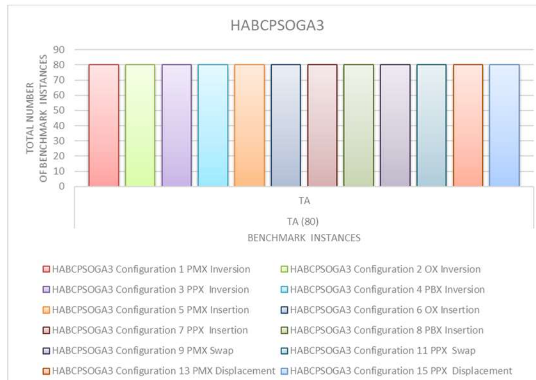

Figure 8: The Obtained Results Of HABCPSOGA3 In Configuration X, X= {1,… , 9, 11, 13, 15, 16} To Solve TA (80) Instances.

As follows from the Figure 8:

- ✓ The proposed method HABCPSOGA3 that used OX with swap mutation or displacement mutation and the HABCPSOGA3 that used PBX with swap mutation or displacement mutation are produced bad results than the proposed method that used OX with insertion mutation or inversion mutation.
- ✓ The proposed method HABCPSOGA3 that used OX with swap mutation or displacement mutation and the HABCPSOGA3 that used PBX with swap mutation or displacement mutation are produced bad results than the HABCPSOGA3 that used PBX with insertion mutation or with inversion mutation.
- ✓ The proposed method HABCPSOGA3 that used OX with swap mutation or displacement mutation and the HABCPSOGA3 that used PBX with swap mutation or displacement mutation are produced bad results than the HABCPSOGA3 that used others crossover operators (PMX, PPX) with others mutation operators (swap, inversion, insertion, displacement).

The results show that the proposed methods HABCPSOGA4 and HABCPSOGA5 in configuration 2, configuration 4, configuration 14 and configuration 16 (that used OX with inversion

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mutation or displacement mutation and that used PBX with inversion mutation or displacement mutation) are given 100% results equal to the best known solution in TA (80) instances as shown in Figure 9.

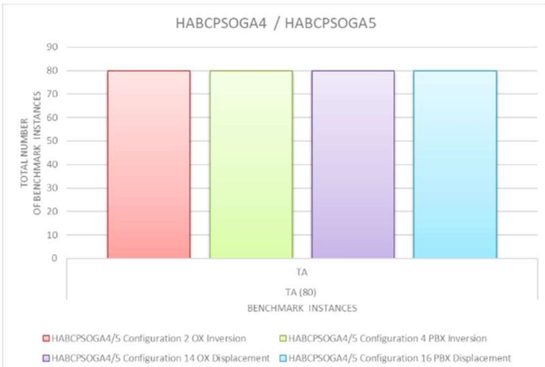

Figure 9: The Obtained Results Of HABCPSOGA4 and HABCPSOGA5 In Configuration 2, Configuration 4, Configuration 14 And Configuration 16 To Solve TA (80) Instances.

As follows from the Figure 9:

- ✓ The proposed methods HABCPSOGA4 and HABCPSOGA5 that used OX with inversion mutation or displacement mutation and that used PBX with inversion mutation or displacement mutation are produced better results than the proposed methods that used the PPX with others mutation operators.
- ✓ The proposed methods HABCPSOGA4 and HABCPSOGA5 that used OX with inversion mutation or displacement mutation and that used PBX with inversion mutation or displacement mutation are produced better than the proposed methods that used MPX with others mutation operators.
- ✓ The proposed methods HABCPSOGA4 and HABCPSOGA5 that used OX with inversion mutation or displacement mutation and that used PBX with inversion mutation or displacement mutation are produced better than the proposed methods that used PBX with insertion mutation or swap mutation.
- ✓ The proposed methods HABCPSOGA4 and HABCPSOGA5 that used OX with inversion mutation or displacement mutation and that used PBX with inversion mutation or displacement mutation are produced better results than the proposed methods that used the OX with insertion mutation or swap mutation.

The results show that the proposed methods HABCPSOGA7 and HABCPSOGA8 in all configurations except in configuration 2, configuration 4, configuration 6 and configuration 8 are given 100% results equal to the best known solution on TA (80) instances as shown in Figure 10.

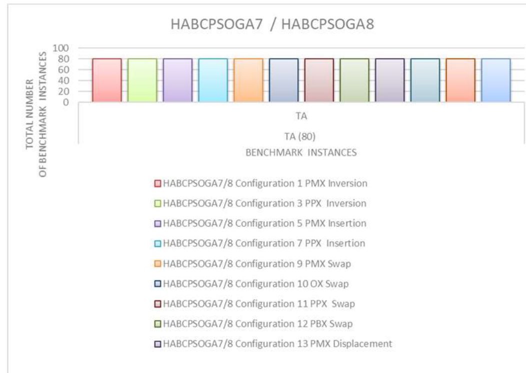

Figure 10: The Obtained Results Of HABCPSOGA7 And HABCPSOGA8 In Configuration X, X= {1, 3, 5, 7, 9, 10, 11, 12, 13, 14, 15, 16} To Solve TA (80) Instances.

As follows from the Figure 10:

- ✓ The proposed methods HABCPSOGA7 and HABCPSOGA8 that used OX with insertion mutation or inversion mutation and that used PBX with insertion mutation or inversion mutation are produced bad results than the proposed methods that used OX with swap mutation or displacement mutation.
- ✓ The proposed methods HABCPSOGA7 and HABCPSOGA8 that used OX with insertion mutation or inversion mutation and that used PBX with insertion mutation or inversion mutation are produced bad results than the proposed methods that used PBX with swap mutation or displacement mutation.
- ✓ The proposed methods HABCPSOGA7 and HABCPSOGA8 that used OX with insertion mutation or inversion mutation and that used PBX with insertion mutation or inversion mutation are produced bad results than the proposed methods that used others crossover operators (PMX, PPX) with others mutation operators (swap, inversion, insertion, displacement).

The results show that the proposed methods HABCPSOGAX, X = 1, 3, 4, 5, 7, 8 in configuration X, X = 1, 3, 5, 7, 9, 11, 13, 15 are given 100% results equal to the best known solution in DMU (80) instances as shown in Figure 11.

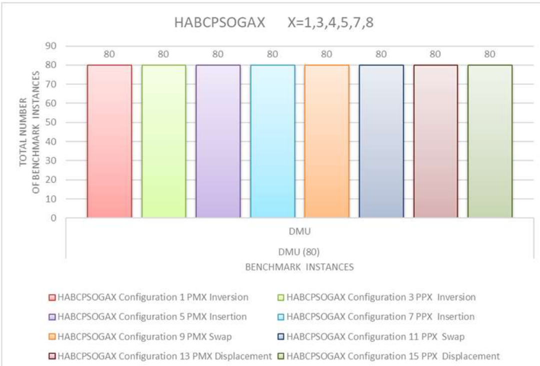

Figure 11: The Obtained Results Of HABCPSOGAX, X = {1, 3, 4, 5, 7, 8} In Configuration X, X= {1, 3, 5, 7, 9, 11, 13, 15} To Solve DMU (80) Instances.

As follows from the Figure 11:

- ✓ The proposed methods HABCPSOGAX, X= 1, 3, 4, 5, 7, 8 that used PPX with all mutation operators are produced better results than the proposed methods that used OX with all mutation operators.
- ✓ The proposed methods HABCPSOGAX, X= 1, 3, 4, 5, 7, 8 that used PPX with all mutation operators are produced better results than the proposed methods that used PBX with all mutation operators.
- ✓ The proposed methods HABCPSOGAX, X= 1, 3, 4, 5, 7, 8 that used PMX with all mutation operators are produced better results than the proposed methods that used OX with all mutation operators.
- ✓ The proposed methods HABCPSOGAX, X= 1, 3, 4, 5, 7, 8 that used PMX with all mutation operators are produced better results than the proposed methods that used PBX with all mutation operators.

The ranking of the proposed methods HABCPSOGA in terms of performance is illustrated in Figure 12 and in the Table 5.

The authors' attention was concentrated not only to develop multi hybridization of swarm intelligence methods to solve job shop scheduling problems but also to make an in-depth analysis for verifying how the multi hybridization of swarm intelligence methods influence the resolution of defined problem.

Summing up the results according to the ranking of the proposed methods HABCPSOGA in terms of performance, it can be concluded that:

- ✓ The proposed methods HABCPSOGA hybridized in its two phases (employed bees phase and scout bees phase) that used crossover operator and mutation operator in employed bees phase and that used position and velocity updating process in scout bees phase are produced the best results than the proposed methods HABCPSOGA hybridized in its two phases (employed bees phase and scout bees phase) that used position and velocity updating process type in employed bees phase and that used crossover operator and mutation operator in scout bees phase.
- ✓ The proposed methods HABCPSOGA hybridized in its two phases (employed bees phase and scout bees phase) that used crossover operator and mutation operator in employed bees phase and that used position and velocity updating process in scout bees phase are produced the best results than the proposed methods HABCPSOGA hybridized in its two phases (employed bees phase and scout bees phase or employed bees phase and onlooker bees phase or onlooker bees phase and scout bees phase) that used others disposition of crossover operator and mutation operator, position and velocity updating process in its two phases.
- ✓ The proposed methods HABCPSOGA hybridized in its two phases (employed bees phase and onlooker bees phase) that used position and velocity updating process in employed bees phase and that used crossover operator and mutation operator in onlooker bees phase are produced the best results than the proposed methods HABCPSOGA hybridized in its two phases (employed bees phase and onlooker bees phase) that used position and velocity updating process in onlooker bees phase and that used crossover operator and mutation operator in employed bees phase.
- ✓ The proposed methods HABCPSOGA hybridized in its two phases (onlooker bees phase and scout bees phase) that used position and velocity updating process in scout bees phase and that used crossover operator and mutation operator in onlooker bees phase are produced the best results than the proposed methods HABCPSOGA hybridized in its two phases (onlooker bees phase and scout bees phase) that used position and velocity updating process in onlooker bees phase and that used crossover operator and mutation operator in scout bees phase.

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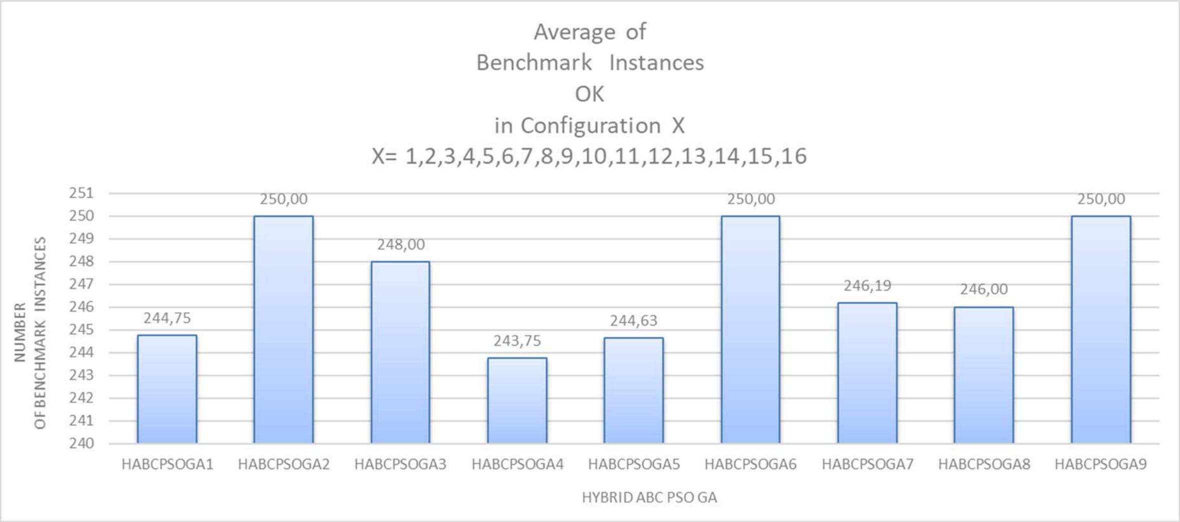

Figure 12: The Ranking Of The Proposed Methods.

Table 5: The Ranking Of The Proposed Methods According To The Hybridization Number

Ranking	Hybrid ABC PSO GA	ABC			Total Number of Benchmark Instances	
		Employed bees phase	Onlooker bees phase	Scout bees phase		
1	HABCPSOGA4	GA	GA	PSO	250,00	100,00%
1	HABCPSOGA6	GA	PSO	GA	250,00	100,00%
1	HABCPSOGA9	PSO	GA	GA	250,00	100,00%
2	HABCPSOGA3	GA		PSO	248,00	99,20%
3	HABCPSOGA7	PSO	GA		246,19	98,48%
4	HABCPSOGA8	PSO		GA	246,00	98,40%
5	HABCPSOGA1		GA	PSO	244,75	97,90%
6	HABCPSOGA5		PSO	GA	244,63	97,85%
7	HABCPSOGA4	GA	PSO		243,75	97,50%

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- ✓ The proposed methods HABCPSOGA hybridized in its three phases are produced the best results in all configurations regardless if HABCPSOGA are employed in its employed bees phase, onlooker bees phase and scout bees phase, crossover operator and mutation operator, or position and velocity updating process.
- ✓ The proposed methods HABCPSOGA hybridized in its three phases are produced the best result in all configurations regardless of crossover operator type and mutation operator type.
- ✓ The proposed methods HABCPSOGA hybridized in its three phases are produced the best results than the proposed methods HABCPSOGA hybridized in its two phases.

The ranking of the proposed methods HABCPSOGA in terms of performance compared with the methods HABCGA available in the literature [51] is demonstrated in the Table 6.

The findings of our research are quite convincing, and thus the following conclusions can be drawn :

- ✓ The proposed methods HABCPSOGA hybridized in its three phases are produced the equal results to the methods HABCGA hybridized in its three phases, in all configurations regardless of crossover operator type and mutation operator type.
- ✓ The proposed methods HABCPSOGA hybridized in its three phases (regardless if HABCPSOGA are employed in its employed bees phase, onlooker bees phase and scout bees phase, crossover operator and mutation operator, or position and velocity updating process) are produced the equal results to the methods HABCGA hybridized in its three phases (HABCGA are employed in its employed bees phase, onlooker bees phase and scout bees phase, crossover operator and mutation operator) in all configurations.
- ✓ The methods HABCGA hybridized in its two phases (employed bees phase and onlooker bees phase) that used crossover operator and mutation operator in these two phases are produced the best results than the proposed methods HABCPSOGA hybridized in its two phases (employed bees phase and onlooker bees phase) that used position and velocity updating process type in employed bees phase and that used crossover operator and mutation operator in onlooker bees phase.
- ✓ The methods HABCGA hybridized in its two phases (employed bees phase and onlooker bees phase) that used crossover operator and mutation operator in these two phases are produced the best results than the proposed methods HABCPSOGA hybridized in its two phases (employed bees phase and onlooker bees phase) that used crossover operator and mutation operator in employed bees phase and that used position and velocity updating process type in onlooker bees phase.
- ✓ The proposed methods HABCPSOGA hybridized in its two phases (employed bees phase and scout bees phase) that used crossover operator and mutation operator in employed bees phase and that used position and velocity updating process in scout bees phase are produced the best results than the methods HABCGA hybridized in its two phases (employed bees phase and scout bees phase) that used crossover operator and mutation operator in these two phases.
- ✓ The proposed methods HABCPSOGA hybridized in its two phases (employed bees phase and scout bees phase) that used position and velocity updating process in employed bees phase and that used crossover operator and mutation operator in scout bees phase are produced the best results than the methods HABCGA hybridized in its two phases (employed bees phase and scout bees phase) that used crossover operator and mutation operator in these two phases.
- ✓ The methods HABCGA hybridized in its two phases (employed bees phase and scout bees phase) that used crossover operator and mutation operator in these two phases are produced the best results than the rest of proposed methods HABCPSOGA hybridized in its two phases.
- ✓ The proposed methods HABCPSOGA hybridized in its two phases (onlooker bees phase and scout bees phase) that used crossover operator and mutation operator in onlooker bees phase and that used position and velocity updating process in scout bees phase are produced the best results than the methods HABCGA hybridized in its two phases (onlooker bees phase and scout bees phase) that used crossover operator and mutation operator in these two phases.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table 6: The Ranking Of The Proposed Methods HABCPSOGA In Terms Of Performance Compared With The Method HABCGA

Ranking	Hybrid ABC PSO GA	ABC			Total Number of Benchmark Instances	
		Employed bees phase	Onlooker bees phase	Scout bees phase		
1	HABCPSOGA4	GA	GA	PSO	250,00	100,00%
1	HABCPSOGA6	GA	PSO	GA	250,00	100,00%
1	HABCPSOGA9	PSO	GA	GA	250,00	100,00%
1	HABCGA3	GA	GA	GA	250,00	100,00%
2	HABCGA2	GA	GA		249,50	99,80%
3	HABCPSOGA3	GA		PSO	248,00	99,20%
4	HABCPSOGA7	PSO	GA		246,19	98,48%
5	HABCPSOGA8	PSO		GA	246,00	98,40%
5	HABCGA7	GA		GA	246,00	98,40%
6	HABCPSOGA1		GA	PSO	244,75	97,90%
7	HABCPSOGA5		PSO	GA	244,63	97,85%
8	HABCPSOGA4	GA	PSO		243,75	97,50%
9	HABCGA5		GA	GA	242,31	96,93%
10	HABCGA1	GA			238,69	95,48%
11	HABCGA6			GA	238,38	95,35%
12	HABCGA4		GA		235,06	94,03%

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- ✓ The proposed methods HABCPSOGA hybridized in its three phases and in its two phases are produced the best results than the methods HABCGA hybridized in its one phase by crossover operator and mutation operator.
- ✓ The proposed methods HABCPSOGA hybridized in its two phases (onlooker bees phase and scout bees phase) that used position and velocity updating process in onlooker bees phase and that used crossover operator and mutation operator in scout bees phase are produced the best results than the methods HABCGA hybridized in its two phases (onlooker bees phase and scout bees phase) that used crossover operator and mutation operator in these two phases.

4. CONCLUSION

The job shop scheduling problem represents a challenge for the researchers, which has been known as an NP-hard. Due to its complexity, hybrid techniques for solving this type of problem are required.

The aim of paper is to establish multi hybridization of swarm intelligence methods HABCPSOGA to solve job shop scheduling problems. The performance of proposed approaches are evaluated by applying it to all well-known benchmark instances and by comparing theirs results with the results of others methods namely HABCGA available in the literature.

Based on the results, it can be concluded that the research into multi hybridization of swarm intelligence methods to solve job shop scheduling problems has been very successful.

The finding supports the theory that the multi hybridization of swarm intelligence methods outperforms the results that were published in the literature and that is broadly consistent with the major investigation which have demonstrated that the hybridization improves the effectiveness of the technique.

The paper presents a pilot study for verifying how the multi hybridization influence the resolution of job shop scheduling problem.

On the basis of the promising findings presented in this paper, work on multi hybridization is continuing and will be presented in future papers.

REFRENCES:

[1] R. Kumar, and D. Sankha, "A Genetic Algorithm-Based Approach for Optimization of Scheduling in Job Shop Environment", *Journal of Advanced Manufacturing Systems*, Vol. 10, No. 2, 2011, pp. 223-240.

[2] M. Gen, and R. Cheng, "Genetic Algorithms and Engineering Optimization", *John Wiley & Sons*, *Inc*., *New York*. 2000.

[3] M. Repinsek, S.H. Liu, and M. Mernik, "Exploration and exploitation in evolutionary algorithms: A survey". *ACM Computing Surveys,* Vol. 45, No. 3, 2013, pp. 1-33.

[4] E. Talbi, "A Unified Taxonomy of Hybrid Metaheuristics with Mathematical Programming, Constraint Programming and Machine Learning", *Hybrid Metaheuristics. Heidelberg: Springer*; 2013

[5] T. Bagchi, "*Multiobjective Scheduling By Genetic Algorithm* (1999 edition)", New York: Springer US, 1999.

[6] P. Brucker, and B. Jurisch, "A branch and bound algorithm for the job-shop scheduling problem", *Discrete Applied Mathematics*, Vol. 49, No. 1-3, 1994, pp. 107-127.

[7] M.E. Aydin, and T.C. Fogarty, "A Distributed Evolutionary Simulated Annealing Algorithm for Combinatorial Optimisation Problems", *Journal of Heuristics*, Vol. 10, No. 3, 2004, pp. 269-292.

[8] T. Satake, K. Morikawa, K. Takahashi, and N. Nakamura, "Simulated Annealing Approach for Minimizing the Makespan of the General Job- Shop", *International Journal of Production Economics,* Vol. 60-61, No. 1, 1999, pp. 515-522.

[9] H. Piroozfard, and K.Y. Wong, "Job shop scheduling problem with late work criterion", *AIP Conference Proceedings*, Vol. 1660, 2015, pp. 050061-1, 050061-5.

[10] C. Bierwith, "A Generalized Permutation Approach to Job ShopScheduling with Genetic Algorithms", *OR Spektrum* Vol. 17, No. 2-3, 1995, pp. 87-92.

[11] J.F. Goncalves, J.M. Mendes, and M. Resende, "A hybrid genetic algorithm for the job shop scheduling problem", *European Journal of Operations Research*, Vol. 167, No. 1, 2004, pp. 77-95.

[12] M. Cwiek, and J. Nalepa, "A fast genetic algorithm for the flexible job shop scheduling problem" *Proceedings of the Companion*

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Publication of the 2014 Annual Conference on Genetic and Evolutionary Computation (GECCO Comp '14) , 2014, pp. 1449-1450.

[13] H. Piroozfard, and K. Y. Wong, "Solving multi-objective job shop scheduling problems using a non-dominated sorting genetic algorithm", *AIP Conference Proceedings*, Vol. 1660, 2015, pp. 050062-1, 050062-6.

[14] L. Asadzadeh, "A local search genetic algorithm for the job shop scheduling problem with intelligent agents", *Computers & Industrial Engineering*, Vol. 85, Issue. C, 2015, pp. 376-383.

[15] E. Nowicki, and C. Smutnicki, "A Fast Taboo Search Algorithm for the Job Shop Problem", *Management Science*, Vol. 42, No. 6, 1996, pp. 797-813.

[16] F. Pezzella, and E. Merelli, "A Tabu Search Method Guided by Shifting Bottleneck for the Job Shop Scheduling Problem", *European Journal of Operational Research*, Vol. 120, No. 2, 2000, pp. 297-310.

[17] V. A. Armentano, and C. Scrich, "Tabu search for minimizing total tardiness in a job shop", *International Journal of Production Economics*, Vol. 63, No. 2, 2000, pp. 131-140.

[18] E. Nowicki, and C. Smutnicki, "An advanced tabu search algorithm for the job shop problem", *Journal of Scheduling*, Vol. 8, No. 2, 2005, pp. 145-159.

[19] C. Zhang, P. Li, Z. Guan, and Y. Rao, "A tabu search algorithm with a new neighborhood structure for the job shop scheduling problem", *Computers & Operations Research*, Vol. 34, No. 11, 2007, pp. 3229-3242.

[20] C. Blum, and M. Sampels, "An Ant Colony Optimization Algorithm for Shop Scheduling Problems", *Journal of Mathematical Modelling and Algorithms*, Vol. 3, No. 3, 2004, pp. 285-308.

[21] A. Colorni, M. Dorigo, V. Maniezzo, and M. Trubian, "Ant System for Job-Shop Scheduling", *Belgian Journal of Operations Research, Statistics and Computer Science (JORBEL),* Vol. 34, No. 1, 1994, pp. 39-53.

[22] T. Satake, K. Morikawa, K. Takahashi, and N. Nakamura, "Neural Network Approach for Minimizing the Makespan of the General Job-Shop", *International Journal of Production Economics*, Vol. 33, No. 1-3, 1994, pp. 67-74.

[23] J. Adams, E. Balas, and D. Zawack, "The Shifting Bottleneck Procedure for Job Shop Scheduling", *Management Science,* Vol. 34, No. 38, 1988, pp. 391-401.

[24] W. Huang, and A. Yin, "An Improved Shifting Bottleneck Procedure for the Job Shop Scheduling Problem", *Computers & Operations Research*, Vol. 31, No. 12, 2004, pp. 2093-2110.

[25] E. Balas, and A. Vazacopoulos, "Guided Local Search with Shifting Bottleneck for Job Shop Scheduling", *Management Science*, Vol. 44, No. 2, 1998, pp. 262-275.

[26] R.M. Aiex, S. Binato, and M.G.C. Resende, "Parallel GRASP with Path-Relinking for Job Shop Scheduling", *Parallel Computing*, Vol. 29, No. 4, 2003, pp. 393-430.

[27] U. Dorndorf, E. Pesch, and T. Phan-Huy, "Constraint Propagation and Problem Decomposition: A Preprocessing Procedure for the Job Shop Problem", *Annals of Operations Research*, Vol. 115, 2002, pp. 125-145.

[28] Y. Zhou, H. Chen, and G. Zhou, "Invasive weed optimization algorithm for optimization no-idle flow shop scheduling problem", *Neurocomputing*, Vol. 137, No. 0, 2014, pp. 285-292.

[29] Y. Nagata, and S. Tojo, "Guided ejection search for the job shop scheduling problem", In: Cotta, C., Cowling, P. (eds.) EvoCOP. LNCS, Springer, Heidelberg. Vol. 5482, 2009, pp. 168-179.

[30] R. Hunt, M. Johnston, and M. Zhang, "Evolving "less-myopic" scheduling rules for dynamic job shop scheduling with GP", *in Proc. GECCO.ACM*, 2014, pp. 927-934.

[31] G.C. Luh, and C.H. Chueh, "A multi-modal immune algorithm for the job-shop scheduling problem", *Information Sciences*, Vol. 179, No. 10, 2009, pp. 1516-1532.

[32] C.C. Coello, D. Rivera, and N. Cortés, "Use of an Artificial Immune System for Job Shop Scheduling", *in Artificial Immune Systems*.,J. Timmis, P. Bentley, and E. Hart, Eds., ed: Springer Berlin Heidelberg, Vol. 2787, 2003, pp. 1-10.

[33] T.L. Lin, S.J. Horng, K. Tzong-Wann, Y.H. Chen, R.S. Run, R.J. Chen, J.L. Lai, and I.H. Kuo, "An efficient job-shop scheduling algorithm based on particle swarm optimization", *Expert Systems with Applications*, Vol. 37, No. 3, 2010, pp. 2629-2636.

[34] S. Mekni, B.F. Chaâr, and M. Ksouri, "Flexible job-shop scheduling with TRIBES-PSO approach", *Journal of Computing*, Vol. 3, No. 6, 2011, pp. 97-105.

[35] M. Akhshabi, and J. Khalatbari, "A particle swarm optimization algorithm for solving flexible job-shop scheduling problem", *Journal of Basic and Applied Scientific Research* Vol. 1, No. 12, 2011, pp. 3240-3244.

[36] A. Sadrzadeh, "Development of both the AIS and PSO for solving the flexible job shop scheduling problem", *Arabian Journal for Science and Engineering*, Vol. 38, No. 12, 2013, pp. 3593-3604

[37] F. Zammori, M. Braglia, and D. Castellano, "Harmony search algorithm for single-machine scheduling problem with planned maintenance", *Computers & Industrial Engineering*, Vol. 76, Issue. C, 2014, pp. 333-346.

[38] H. Piroozfard, and K.Y. Wong, "An imperialist competitive algorithm for the job shop scheduling problems", *IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 2014, pp. 69-73.

[39] H.C. Lee, and C.H. Dagli, "A parallel genetic-neuro scheduler for job-shop scheduling problems", *International Journal of Production Economics*, Vol. 51, No. 3, 1997, pp. 115-122.

[40] I. Sabuncuoglu, and M. Bayiz, "Job shop scheduling with beam search", *European Journal of Operational Research*, Vol. 118, No. 2, 1999, pp. 390-412.

[41] B. Ombuki, and M. Ventresca, "Local Search Genetic Algorithms for the Job Shop Scheduling Problem", *Applied Intelligence*, Vol. 21, No. 1, 2004, pp. 99-109.

[42] L. Liu, and Y. Xi, "A Hybrid Genetic Algorithm for Job Shop Scheduling Problem to Minimize Makespan", *The Sixth World Congress on Intelligent Control and Automation, WCICA*, 2006, pp. 3709-3713.

[43] K.L. Huang, and C.J. Liao, "Ant colony optimization combined with taboo search for the job shop scheduling problem", *Computers & Operations Research*, Vol. 35, No. 4, 2008, pp. 1030-1046.

[44] J.C. Beck, T.K. Feng, and J.P. Watson, "Combining constraint programming and local search for job-shop scheduling", *INFORMS Journal on Computing*, Vol. 23, No. I, 2011, pp. 1-14.

[45] T. Rakkiannan, and B. Palanisamy, "Hybridization of genetic algorithm with parallel implementation of simulated annealing for job shop scheduling", *American journal of Applied Sciences*, Vol. 9, No. 10, 2012, pp. 1694-1705.

[46] H. Karimi, S.H.A. Rahmati, and M. Zandieh, "An efficient knowledge based algorithm for the flexible job shop scheduling problem", *Knowledge-Based Systems*, Vol. 36, No. 0, 2012, pp. 236-244.

[47] J. Yang, L. Sun, H.P. Lee, Y. Qian, and Y. Chun Liang, "Clonal selection based memetic algorithm for job shop scheduling problems", *Journal of Bionic Engineering*, Vol. 5, No. 2, 2008, pp. 111-119.

[48] J. Nalepa, and Z. J. Czech, "New selection schemes in a memetic algorithm for the vehicle routing problem with time windows", *in Proc. ICANNGA , ser. Lecture Notes in Computer Science. Springer*, Vol. 7824, 2013, pp. 396-405.

[49] J. Nalepa, and M. Kawulok, "A memetic algorithm to select training data for support vector machines", *in Proc. GECCO, ser. GEC CO ' 14. ACM*, 2014, pp. 573-580.

[50] J. Nalepa, and M. Blocho, "Co-operation in the parallel memetic algorithm", *International Journal of Parallel Programming*, Vol. 47, No. 2, 2014, pp. 1-28.

[51] H. Jebari, S.R. Elazzouzi, H. Samadi, S. Rekiek, "The search of balance between diversification and intensification in artificial bee colony to solve job shop scheduling problem", *Journal of Theoretical and Applied Information Technology*, Vol. 97, No. 2, 2019, pp. 658-673.

[52] J. Kennedy, and R. Eberhart, "Particle swarm optimization", *Proceedings of IEEE International Conference on Neural Networks*, Vol. 4, 1995, pp. 1942-1948.

[53] E. Bonabeau, M. Dorigo, and T. Theraulaz, "From Natural to artificial Swarm Intelligence", *Oxford University Press, New York*, 1999.

[54] M. Dorigo, and M. Brittari, "Ant Colony Optimization and swarm intelligence", *Springer*, 2004.

[55] D. Karaboga, and B. Basturk, "A powerful and efficient algorithm for numerical function

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

optimization: artificial bee colony (abc) algorithm", *Journal of Global Optimization*, Vol. 39, No. 3, 2007, pp. 459-471.

[56] J.A. Holland, (in press), "Adaptation in natural and artificial systems", MIT Press, (1975).

[57] L. Asadzadeh, and K. Zamanifar, "An agent-based parallel approach for the job shop scheduling problem with genetic algorithms", *Mathematical and Computer modeling*, Vol. 52, No. 11-12, 2010, pp. 1957-1965.

[58] H. Yu, and W. Liang, "Neural network and genetic algorithm based approach to expand job shop scheduling problem", *Computers & Industrial Engineering*, Vol. 39, No. 3-4, 2001, pp. 337-356.

[59] Y. Demir, and S.K. İşleyen, "An effective genetic algorithm for flexible job-shop scheduling with overlapping in operations", *International Journal of Production Research*, Vol. 52, No. 13, 2014, pp. 3905-3921.

[60] I.M. Oliver, D.J. Smith, and J.R.C. Holland, "Study of permutation crossover operators on the traveling salesman problem", *Proceedings of the second International Conference on Genetic Algorithms and their applications*. 1987, pp. 28-31.

[61] G. Cavory, R. Dupas, and G. Goncalves, "A genetic approach to solving the problem of cyclic job shop scheduling with linear constraints", *European Journal of Operational Research*, Vol. 161, No. 1, 2005, pp. 73-85.

[62] G. Zhang, L. Gao, and Y. Shi, "An effective genetic algorithm for the flexible job-shop scheduling problem", *Expert Systems with Applications*, Vol. 38, No. 4, 2011, pp. 3563-3573.

[63] U. Dorndorf, and E. Pesch, "Evolution based learning in a job shop scheduling environment", *Computers and Operation Research*, Vol. 22, No. 1, 1995, pp. 25-40.

[64] A.C. Nearchou, "The effect of various operators on the genetic search for large scheduling problems", *International Journal of Production Economics*, Vol. 88, No. 2, 2004, pp. 191-203.

[65] H. Fisher, and G.L. Thompson, "Industrial Scheduling", *Englewood Cliffs, NJ: Prentice-Hall,* 1963.

[66] J. Adams, E. Balas, and D. Zawack, "The shifting bottleneck procedure for job-shop scheduling", *Management Science*, Vol. 34, No. 3, 1988, pp. 391-401.

[67] T. Yamada, and R. Nakano, "A genetic algorithm applicable to large-scale job-shop problems", *Proceedings of the second International Workshop on Parallel Problem Solving from Nature (PPSN'2)*. Brussels, Belgium, 1992, pp. 281-290.

[68] S. Lawrence, "Resource constrained project scheduling: an experimental investigation of heuristic scheduling techniques", *Pittsburgh: Graduate School of Industrial Administration*, 1984.

[69] D. Applegate, and W. Cook, "A computational study of the job-shop scheduling problem", *ORSA Journal on Computing*, Vol. 3, No. 2, 1991, pp. 149-156.

[70] R.H. Storer, D. Wu, and R. Vaccari, "New search spaces for sequencing problems with application to job shop scheduling", *Management Science*, Vol. 38, No. 10, 1992, pp. 1495-1509.

[71] E.D. Taillard, "Parallel taboo search techniques for the job shop scheduling problem", *ORSA Journal on Computing*, Vol. 6, No. 2, 1994, pp. 108-117.

[72] E. Demirkol, S. Mehta, and R. Uzsoy, "A computational study of shifting bottleneck procedures for shop scheduling problems", *Journal of Heuristics*, Vol. 3, No. 2, 1997, pp. 111-137.

[73] J. Carlier, and E. Pison, "An algorithm for solving the job shop problem", *Management Science*, Vol. 35, No. 2, 1989, pp. 164-176.