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A New Hybrid Optimization Algorithm to Solve Lot Sizing Problems

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Abstract: Inventory management is a completely crucial feature that determines the fitness of the deliver chain as well as the influences the economic fitness of the balance sheet. it is an idle inventory of physical items that contain financial fee, and is held in numerous bureaucracy via an company in its custody looking forward to packing, processing, transformation, use or sale in a future point of time .Improper inventory management leads to loss. Those losses can be minimized/eliminated through Lot Sizing technique which will help in proper maintenance if inventory management. Lot sizing (or batching) is the manner of enhancing the net requirement portions before they're translated into deliberate orders in a material requirement planning system. If net requirements have been translated directly into deliberate orders, it would bring about manufacturing component schedules and purchasing schedules that did now not take any account of the fee of system setups or the value of ordering. To take account of the whole expenses of dealing with the materials, i.e., holding expenses and ordering or setup expenses, batch-sizing policies or ordering rules may additionally need to be implemented to the net requirements to provide planned orders for the producing or purchasing of items.

Many heuristic strategies have been evolved in the past to solve lot sizing problems, however many of them were failed in its successful implementation. The present works aims to discover most appropriate inventory plan, which take the minimization of general setup expenses and inventory holding prices. On this undertaking, Hybrid algorithm has been applied to clear up the problems and triumph over the issues.

Keywords: Inventory management; Lot-sizing; Multi-objective Lot Sizing Problem; Optimization; Particle Swarm Optimization; Harmony Search Algorithm.

I. INTRODUCTION

All the functions in an organization are interlaced and connected to one another and often overlap with each other. Some key day-to-day tasks such as logistics, inventory management, and supply chain management form the chief support of an organization. One of the routine problems encountered by maximum number of the organization is maintaining sufficient inventory. There is no proper solution to face this problem since the conditions at each organization are unique and include different features and limitations. Inventory management call for continuous and mindful evaluation of both external and internal factors and standard control through planning and review. Most of the inventory managing organizations, employs a separate department in order to continuously monitor, control and review inventory and interface with procurement, production, and finance departments. To formulate accurate, effective, and efficient inventory plan in such complex conditions, it becomes necessary to make use of system analysis and development of an organized approach to the problem. There is a much required need for developing new and effective methods for modelling systems associated with logistics, supply chain management, and inventory control and the solution to such critical issues rely on the conditions of organization's features, limitations and their practices. This paper focuses on a new hybrid optimization algorithm developed by collaborating Particle Swarm Optimization (PSO) and Harmony Search Algorithm (HSA) which are inspired from nature and music respectively.

II. INVENTORY MANAGEMENT

Inventory management is a key function that affects the strength of the supply chain as well as influences the financial condition of the organization. Modern day inventory is managed by advanced system applications, which needs a continuous and cautious evaluation of both external and internal factors. Need for inventory occurs at different stages in an organization. In case of a manufacturing industry, inventory may be in the form of raw materials, work in progress or finished goods. Besides this, there is also a need to keep the spare parts for servicing the products. Inventory procurement, storage and its management in any organization for smooth supply chain management comes with huge costs. Inventory management activities are based on managing the following costs efficiently:

A. Ordering cost
B. Carrying cost
C. Shortage or stock out cost of replenishment.

III.HYBRID OPTIMIZATION ALGORITHM

A. Methodology

Soft Computing is a blend of methodologies that were designed to version and enable answers to the real world difficulties, which aren't modelled, or too difficult to model, mathematically. Soft computing strategies are extra powerful and efficient as they provide the feasible and much less steeply-priced answers as compared to hard computing strategies[1]. Soft computing techniques are more effective as they provide the possible and less priced solutions as compared to other computing techniques. There are numerous methods of soft computing which may be implemented to resolve lot-sizing problem. Some of the broadly used strategies are:

1) Fuzzy Logics
2) Genetic Algorithm
3) Harmony Search Algorithm
4) Simulated Annealing method
5) Particle Search Optimization
6) Ant Colony Optimization
7) Baysien network
8) Differential evolution

The method approached to solve the considered problems involves the collaboration of two different techniques making it a hybrid optimization technique. The approached techniques are evolutionary, one being inspired from nature and another from musicians. They are:

B. Particle swarm optimization (Nature Inspired)

C. Harmony Search Algorithm (Music inspired)

1) *Particle Swarm Optimization:* Particle Swarm Optimization (PSO) is a population based entirely stochastic optimization methodology developed with the aid of Dr. Eberhart and Dr. Kennedy in 1995[2]. PSO bonds many similarities with evolutionary computation strategies which includes Genetic Algorithms (GA). The device is set with a populace of random solutions and searches for target by means of updating generations. But, in contrast to GA, PSO has no evolution operators such as crossover and mutation. In PSO, the ability solutions, called particles, fly through the search space through following the modern best particles. In comparison to GA, the benefits of PSO are that PSO is straightforward to put into effect and there are few parameters to alter. The flow chart in Fig. x gives clear understanding on how the method works to find the best possible outcomes.
2) *Harmony Search Algorithm:* The improvisation process of Jazz musicians initially inspired the HS algorithm. Each musician resembles to each decision variable; musical instrument's pitch range corresponds to decision variable's value range; musical harmony at particular time corresponds to solution vector at certain iteration; and audience's aesthetic corresponds to objective function. Just as musical harmony is enhanced time after time, solution vector is enhanced iteration by iteration [3].
3) *Hybrid Algorithm:* The hybrid algorithm proposed in the present work collaborates the search methods of both the particle search optimisation and the harmony search algorithm in order to find the best possible outcome for the problem considered. The working of proposed algorithm is described briefly in the implementation section below.

D. Implementation

The platform for proposed algorithm is a PC with 3.1GHz CPU and 8GB RAM with Windows 10 Operation System. The algorithm is coded and executed in Matlab R2017a.

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A numerical example has been illustrated to present the working of hybrid optimization algorithm. Initially, the LSP is defined, the demand of the product is as shown in the table 1. The holding cost and the ordering cost are taken as $1 per unit per period and $100 per order respectively.

TABLE I
DEMAND OF THE PRODUCT

Period	1	2	3	4	5	6
Demand	60	40	80	90	50	40

The simplest model of inventory lost sizing problem is single item with no shortages allowed. Mathematical formulation for such a model takes the following form.

$$\min\left(\sum_{i=1}^{n} A_{xi} + cI_i\right) \qquad (1)$$

Subject to:

$$I_0 = 0 \qquad (2)$$

$$I_{i-1} + x_i Q_i - I_i = R_i \qquad \forall_i \qquad (3)$$

$$I_i \geq 0 \qquad \forall_i \qquad (4)$$

$$Q_i \geq 0 \qquad \forall_i \qquad (5)$$

$$x_i \in 0\{0,1\} \qquad \forall_i \qquad (6)$$

where,

n number of periods
A setup cost per order
C carrying cost per unit per period
R_i requirements for period i
I_i ending inventory
x_i is 1 if order is placed in period i, else 0

The objective function (1) induces a penalty charge A for each order placed and c for each unit carried in inventory over the next period. Equation (2) specify that no initial inventory is available. Equation (3) tries to satisfy the net requirements. The order quantity, Qj covers all the requirements until the next order. Equation (4) is the non-negativity restriction on the inventory levels (no shortages allowed), (5) is the non-negativity restriction on the order quantities, and (6) forces the decision variable z_i to be 0 (do not place an order on period i) or 1 (place an order). Given that the initial inventory is zero, $I_O = 0$, it is observed that $z_1 = 1$ by (3) if $R_1 > 0$. Due to the minimization nature of the problem, the ending inventory at each period is minimized to avoid the penalty charge c, particularly I, = 0. [4].

The initial particles in the swarm are generated with solution ($x_{i1}^k, x_{i2}^k, \ldots\ldots, x_{id}^k$), where i, d and k represents solution, particle position and iteration respectively. The corresponding velocities ($v_{i1}^k, v_{i2}^k, \ldots\ldots, v_{id}^k$) are developed randomly between the limits [-4,4] as shown in table 2. This limits enhances the local search exploration of the problem space [5].

TABLE III
INITIAL POPULATION OF PARTICLES IS GENERATED

Period	1	2	3	4	5	6
Solution	1	1	1	0	0	0
Velocity	2.1	-1.8	0.8	3.7	-1.8	-2.7
Solution	1	1	0	1	1	1
Velocity	1.8	-2.6	-3.5	1.6	1.1	-0.5
Solution	1	0	0	0	0	1
Velocity	0.5	-1.7	-1.9	3.4	2.8	-0.2

The cost calculations for each particle is carried out as per the solution developed. The following table 3 represents the cost calculation for one particle.

TABLE IIIII
COST CALCULATION FOR ONE PARTICLE

Period	1	2	3	4	5	6	Total Cost
Demand	60	40	80	90	50	40	
Solution	1	1	1	0	0	0	
Velocities	2.1	-1.8	0.8	3.7	-1.1	-2.7	
Quantity	60	40	260	0	0	0	
Inventory	0	0	180	90	40	0	
HC	60	40	310				
OC	100	100	100	0	0	0	
OC+HC	160	140	310				610

Similarly, the cost for each particle is calculated with respect to their corresponding values in solution and is tabulated in table 4.

TABLE IVV
FONT SIZES FOR PAPERS

Particle No	Solution	Cost
1	1 1 1 0 0 0	610
2	1 1 0 1 1 1	580
3	1 0 0 0 0 1	870

The results of each particle is assigned as corresponding particle best in the first iteration and the particle having lowest cost value is assigned as global best of the iteration as shown in table 5.

TABLE V
INITIAL PARTICLE AND GLOBAL BEST

Particle No	Best Solution	Best Cost
1	1 1 1 0 0 0	610
2	1 1 0 1 1 1	580
3	1 0 0 0 0 1	870
Global Best	1 1 0 1 1 1	580

For the second iteration, the velocity of the particle is updated by calculating the change in velocity. Since the binary version of the PSO is applied, we need to use two useful functions i.e., sigmoid function in order to force the real values between 0 and 1, and the linear function to force velocity values inside the applied limits. Change in velocity is calculated as shown below for the first particle at third position.

$$\Delta v_{13}^{k} = r1 \times c1\left(pb_{13}^{k} - x_{13}^{k}\right) + r2 \times c2\left(gb_{13}^{k} - x_{13}^{k}\right)$$

$$\Delta v_{13}^{k} = 0.5 \times 0.5(1-1) + 0.5 \times 0.5(0-1)$$

$$\Delta v_{13}^{k} = -0.25$$

Updated Velocity=Change in velocity + Previous Velocity

$$v_{13}^{k+1} = \Delta v_{13}^{k} + v_{13}^{k}$$

$$v_{13}^{k+1} = 0.8 - 0.25 = 0.55$$

Similarly, the velocities for each particle is updated and its corresponding sigmoid value is obtained in order to develop new solution. The table 6 represents new solution developed using sigmoid function and random numbers (RN) after updating the velocities.

TABLE VV

VELOCITY UPDATING FOR SECOND ITERATION

Period	1	2	3	4	5	6
Vel	2.1	-1.8	0.5	3.9	-1.1	-2.7
Sig	0.8	0.1	0.6	0.9	0.2	0
RN	0.9	0.5	0.1	0.8	0.5	0.1
Soln	1	1	0	1	0	0
Vel	1.8	-1.8	-3.5	1.6	1.1	-0.5
Sig	0.1	0.8	0	0.8	0.7	0.3
RN	0.5	0.7	0.2	0.9	0.9	0.8
Soln	1	0	0	1	1	1
Vel	0.5	-1.7	-1.9	3.4	2.8	0.8
Sig	0.6	0.1	0.1	0.8	0.8	0.6
RN	0.8	0.7	0.6	0.9	0.9	0.3
Soln	1	0	0	0	0	0

Each particle is now evaluated as per the corresponding new solutions obtained as shown in table 6. The table 7 shows the cost values with respect to the new solutions obtained and the particle and global best are updated as shown in table 8.

TABLE VIVI

COST EVALUATION WITH NEW SOLUTIONS

Particle No	Solution	Cost
1	1 1 0 1 0 0	510
2	1 0 0 1 1 1	600
3	1 0 0 0 0 0	970

TABLE VIII

UPDATED PARTICLE AND GLOBAL BEST

Particle No	Best Solution	Best Cost
1	1 1 0 1 0 0	510
2	1 1 0 1 1 1	580
3	1 0 0 0 0 1	870
Global Best	1 1 0 1 0 0	510

The process is repeated until half of the iterations are run. Then the results of PSO is assigned as input to harmony search algorithm for further improvisation of the solution. Note that term harmony will represent the particle in the remaining steps for the ease of understanding. The parameters of HSA such as number of iterations, HMCR(usually 0.7-0.95), PAR(usually 0.1-0.3) are defined initially.

A new solution is developed on basis of HSA conditions as described in section 4.1.1 and the same is illustrated below:

If a random<=HMCR, A new solution from the existing solutions of particle are chosen randomly.

If another random number<PAR, the above generated solution is refined by swapping any two positions in a harmony.

Example: [1 1 0 1 0 0] is changed to [1 0 1 1 0 0], the second and third position are swapped in the first harmony(particle).

If the condition random<=HMCR fails, a new random solution is generated randomly.

A new harmony is represented in the table 9 which is obtained with respect to the above three conditions and its corresponding cost is calculated in a similar manner to that of PSO.

TABLE IX

NEW HARMONY DEVELOPED

Harmony	Cost
1 0 1 1 0 0	470

The new harmony is merged with the harmony memory and are sorted with respect cost values. The sorting helps the best harmony to get the first position in the harmony memory and the worst harmony in last position. This helps in simplifying the process for eliminating worst harmony from the memory. The table 10 shows new harmony memory that includes the values of new harmony.

TABLE X

HARMONY MEMORY SORTED W.R.T COST

Harmony	Solution	Cost
Harmony 4 (new)	1 0 1 1 0 0	470
Harmony 1	1 1 0 1 0 0	510
Harmony 2	1 1 0 1 1 1	580
Harmony 3	1 0 0 0 0 1	870

If the cost of newly developed harmony is better than that of the worst harmony in the memory, the new harmony replaces the worst harmony from the memory. The new harmony memory is shown in table 11.

TABLE XI

NEW HARMONY MEMORY

Harmony	Solution	Cost
Harmony 1	1 1 0 1 0 0	510
Harmony 2	1 1 0 1 1 1	580
Harmony 3	1 0 1 1 0 0	470

The above procedure of improvising is repeated until the termination criteria is reached or until the remaining number of iterations are completed. At last the best harmony results are extracted from the harmony memory which contains best cost and corresponding solution.

IV. RESULTS AND DISCUSSIONS

A. Problem-1

As per the implementation of the proposed hybrid optimization algorithm, the following problem from William Hernandez and Gursel A. Suer [4] is considered in which best cost of $1020 is first observed at iteration 69, 264, 329, 457,598 and 629 for various parameters. The same problem is executed with same holding and ordering costs as per the literature. The demand for different period is as shown in table 12. The population size for both PSO and HSA are taken as 30. Maximum and minimum velocity are taken in the limits [-4,4] and the acceleration constants is taken as 2. The values of HMCR and PAR is taken as 0.85 and 0.2 respectively for executing the second half of the algorithm. The results are discussed in table 13 and figure 1.

TABLE XII
DEMAND OF AN ITEM IN PROBLEM 1

Period	1	2	3	4	5	6	7	8	9	10	11	12
Demand	100	60	40	50	80	70	120	110	150	90	140	50

TABLE XVIIII
BEST COSTS VS ITERATION

Iteration No.	PSO	HSA	HYBRID
1	1110	1090	1150
3	1080	1090	1110
5	1080	1080	1070
10	1070	1050	1070
20	1070	1020	1030
50	1070	1020	1030
100	1070	1020	1030
150	1070	1020	1020
200	1020	1020	1020
250	1020	1020	1020
300	1020	1020	1020

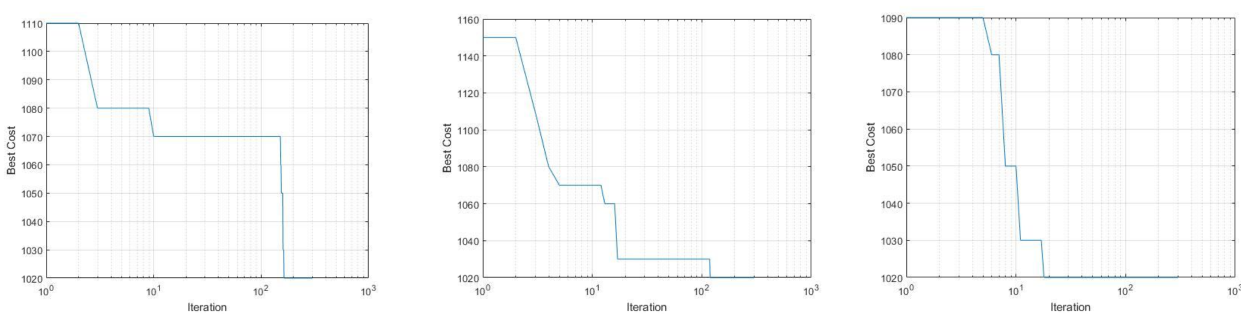

Fig. 1 Best Costs vs Iteration for PSO, HSA, and Hybrid (left to right) for Prob-1

TABLE XIV
BEST COSTS AND EXECUTION TIME FOR PROBLEM 2

	LFL	PSO	HSA	HYBRID
Best Cost	1200	1020	1020	1020
Time(secs)	1	1	1	1

B. Problem-2

A 9x15 multi-level lot sizing problem from Yi Han et al. [6] is considered in which best cost is achieved in the range 2043 to 4834 for various parameters. The BOM structure of the problem is illustrated in figure 2. The problem is executed with same holding and

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ordering costs as per the literature. The demand for different period is as shown in table 15. The population size for both PSO and HSA are taken as 60 as per the literature. Maximum and minimum velocity are taken in the limits ± [(0.1)x(No. of Items)x(No. of Periods)] and the acceleration constants is taken as 2. The values of HMCR and PAR is taken as 0.85 and 0.2 respectively for executing the second half of the algorithm. The results are discussed in table 16 and figure 3. The best costs achieved are tabulated in table 17.

TABLE XV

DEMAND OF A PRODUCT IN PROBLEM 1

Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Demand	32	41	148	36	120	28	32	12	30	10	32	41	148	36	120

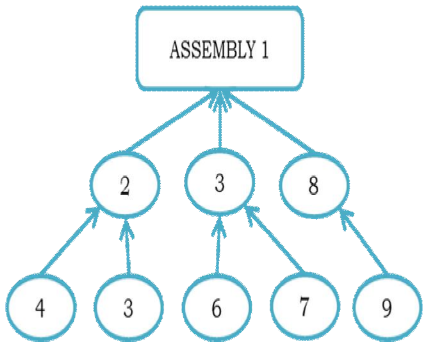

Fig. 2 BOM structure for Prob-2

TABLE XVI

BEST COSTS VS ITERATION

Iteration No.	PSO	HSA	HYBRID
1	3266	2545	2918
3	2660	2545	2370
5	2515	2452	2306
10	2194	2292	2121
20	1954	2292	2121
50	1904	1606	1661
100	1749	1606	1637
200	1749	1602	1602
250	1749	1602	1602
300	1594	1594	1594
500	1594	1594	1594

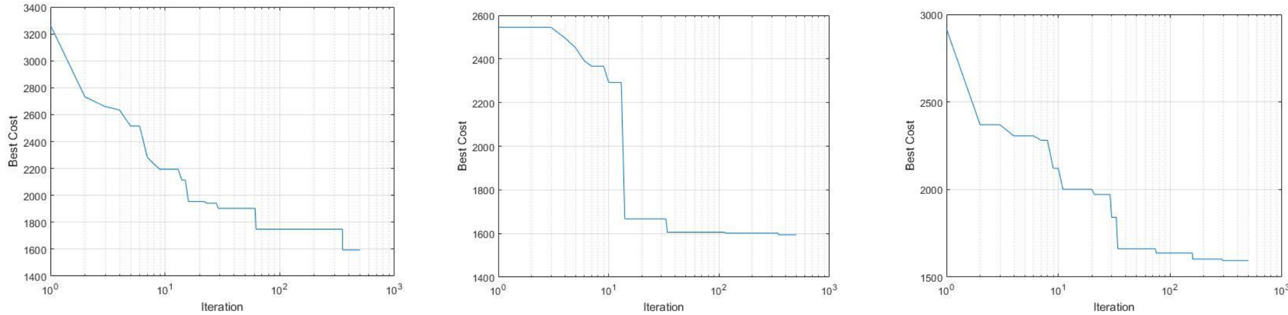

Fig. 3 Best Costs vs Iteration for PSO, HSA, and Hybrid (left to right) for Prob-2

TABLE XVII

BEST COSTS AND EXECUTION TIME FOR PROBLEM 2

	LFL	PSO	HSA	HYBRID
Best Cost	9750	1594	1594	1594
Time(secs)	3	48	31	40

C. Problem-3

The following 44x12 multi-level LSP has been taken from a manufacturing industry. The demand of an assembly and BOM structure is as shown in the table 18 and figure 4. The industry follows lot for lot technique for inventory management. By using the proposed algorithm, the costs have been reduced to large extent as shown in the table 20. The parameters of PSO and HSA are taken similar to that of in problem 1. The results are discussed in table 19,20 and fig 4.

TABLE XVIII

DEMAND OF A PRODUCT IN PROBLEM 1

Period	1	2	3	4	5	6	7	8	9	10	11	12
Demand	8	10	9	11	8	12	11	9	10	8	7	13

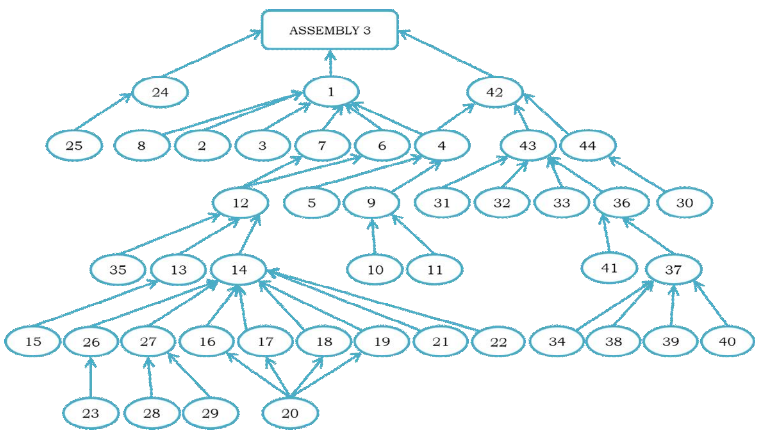

Fig. 2 BOM structure for Prob-2

TABLE XIX

BEST COSTS VS ITERATION

Iteration No.	PSO	HSA	HYBRID
1	42005	19742	42031
3	41754	49671	42031
5	39084	49671	42031
10	39764	49641	42031
20	39764	35759	40559
50	34278	34684	37498
100	34168	33174	31052
200	31579	32923	30764
250	31579	32773	30094
300	31579	31526	29254
500	31579	31526	29254

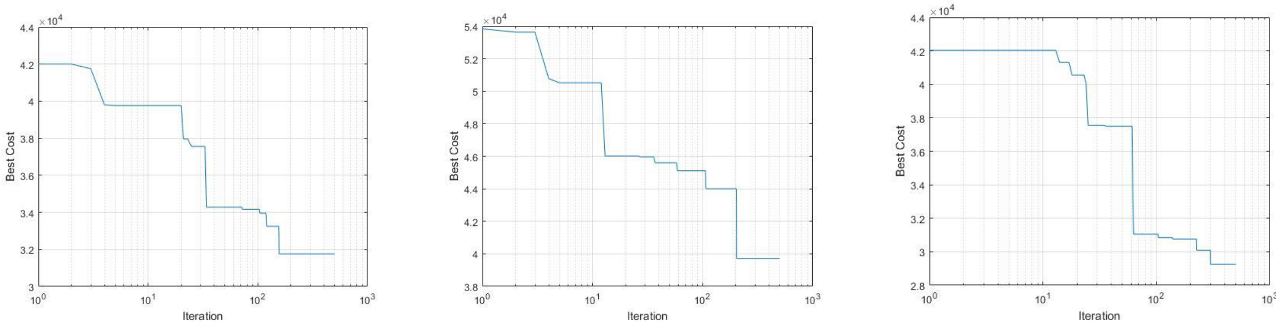

Fig.5 Best Costs vs Iteration for PSO, HSA, and Hybrid (left to right) for Prob-3

TABLE XX

BEST COSTS AND EXECUTION TIME FOR PROBLEM 2

	LFL	PSO	HSA	HYBRID
Best Cost	282200	31579	31526	29254
Time(secs)	7	1508	1268	1435

D. Summary

Each problem has been executed 50 times and the best results are saved. It is observed that hybrid optimization algorithm gave better results than that of PSO and HSA in certain runs. The lot for lot has also been calculated for comparison. Since the coding has been performed in Matlab, the execution time has been reduced to large extent compared to that of in C language.

V. CONCLUSIONS

An attempt is successfully made to develop a new hybrid optimization algorithm by implementing two evolutionary soft computing techniques that are particle swarm optimization and harmony search algorithm. A simple numerical has been illustrated for understanding the working of developed algorithm. A single level and multi-level LSP has been taken from existing literatures and executed to prove the efficiency and accuracy of the developed algorithm.

As per the results observed, it is clear that PSO takes time to reach the optimum results whereas HSA is much more efficient in finding the same. It can be seen that computing time of HSA is comparatively better than PSO. The hybridization of PSO and HSA helped in reducing computing time since the PSO initially moves the position of the particles towards its best position which helps HSA in quickly finding the optimum results. The results achieved were much efficient in terms of computing time compared to the results of the problem considered from the literature. The hybridisation also helped to reduce the number of iterations to be considered which indirectly reduced the computing time since the number of iteration to be executed is directly proportional to the computing time.

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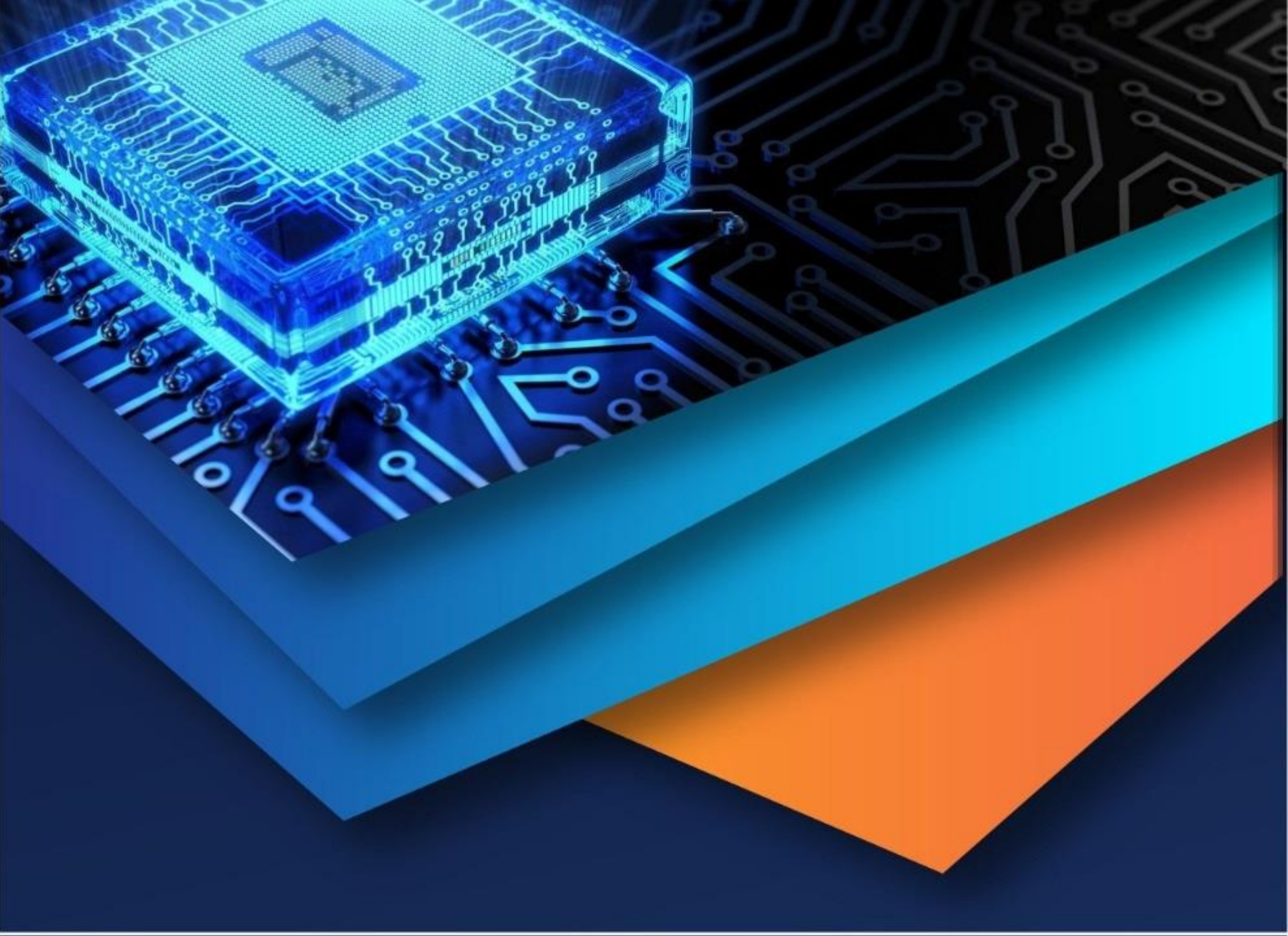

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