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Optimizing a Multi-objective Flow Shop Scheduling Problem by Meta-heuristic Approach

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Abstract **The present research work addresses the formulation of a hybrid meta-heuristic distribution algorithm for the multi-objective flow shop scheduling problem with sequence-dependent setups and backlogging constraints. The aim of research is to minimize dual objectives, process time and cycle time. The present work developed a model to solve the problem using meta-heuristics Teacher Learning based Optimization (TLBO). TLBO optimization is based on the teacher and student learning process. The novel hybrid meta-heuristic algorithm TLBO utilizes the TLBO teacher phase between the migration and mutation phase. The multi-objective problems with sequence-dependent time estimates are NP-hard due to their greater complexity of producing optimal results in reasonable period. The scope of the paper is to deal with NP-hard problems due to their multi-solution and strong neighborhood search capabilities. The proposed meta-heuristic is used to solve eight machine flow shop problem, where the results obtained from the heuristic is compared with the real-time data of the industry and validation of results on each machine is conducted in case study wise. The analytical results indicate the estimation of optimized process time within range of upper and lower bounded limits for part 1 is 2.95 to 9.29 minutes, and for part 2 is 3.48 to 13.68 minutes. The MATLAB software is used for coding the meta-heuristic and evaluating the results. The actual reduction in time reflects the effectiveness of the proposed hybrid algorithm that it is capable of producing optimal results for the multi-objective flow shop problem with time factors and backlogging.**

Keywords — Optimization, Meta-heuristics, Makespan, Multi-objective, and Flow shop scheduling

I. INTRODUCTION

In the real-time scenario, there exist many situations in manufacturing system like due date changes, unexpected job release, machine breakdowns and more significant processing times, than estimated and expected. The cost of production aggregates to high proportion of any firm's expenditure, hence every firm tries to get a proper design of shop and scheduling of jobs on various machines to optimize the task times for long-term and short-term goals. The decision-making approaches and heuristics algorithms for multi-objective scheduling are utilized for optimizing flow shop scheduling problems [1].

The identification of uncertain dynamic scheduling parameters is essential for multi-objective flow shop scheduling. Some challenging factors are [2] (i) computation modelling performance to multi-criteria scheduling problems. (ii) Design of constraints of production scheduling and (iii) grouping and cross-combination of scheduling functional parameters. The meta-heuristic approach can be comprised of algorithm methods such as B&B, PSO, GA, ACO, TS, and many more optimized approaches. The factors causing the algorithms are required for hybrid approach or single-objective. The challenging aspect in novel algorithm approach is hybridization of multi-criteria or multi-objective scheduling approaches [3].

One good example has been set by proposing a scheduling model to optimize pyramidal or v-shaped properties. It is the case of permutation sequence-dependent setup time under flow shop scheduling [4]. A case of parallel modelling flow shop problem has been developed in which the maximum completion time can be minimized under blocking constraints by the application of variable

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neighborhood search algorithm. This is applicable in solving small-size instances too [5].

n-jobs m-machine sequencing problem with a minimum total elapsed time criterion has been proposed a heuristic algorithm for the problem [6]. B&B algorithm is presented for the single machine problem to minimize tardiness. The algorithm uses dual problem which was further formulated as Lagrangian's problem to obtain reasonable solutions and lower bound on the optimal objective value [7]. The ordered flow shop sequencing problem with no in-processing waiting (OFSNW) is a dynamic approach to diminish the mean flow time [8]. A bi-criteria flow shop scheduling problem is proposed where total tardiness and total flow time has to be minimized. A hybrid algorithm was developed by incorporating dominance precedence relationship into a multiple-criteria dynamic programming framework for the problem [9]. The permutation flow shop problem has been addressed with finite buffer capacities. A (B&B) approach of the problem was developed, which is easily capable to solve cyclic problem for the production flow line [10]. The flow shop problem is addressed problem where processing is continuous with due date constraints and makespan criterion. A graphical modelling for the problem along with an extract enumeration algorithm was presented [11]. The continuous memetic algorithm is proposed to resolve multi-objective distributed (PFS) problem known as (MODPFSP) under objectives to reduce makespan and total tardiness [12].

II. LITERATURE MODELS AND ANALYSIS

This paper reviews the contributions made towards multi-objective FSS problems, SDST problems, and backlogging problems in the past few years. As flow-shop environment is common practice in the manufacturing industries, hence important to improve the productivity to achieve profit-worthy status in the economy. The introduction section has been demonstrated the spread of flowshop problem in the diverse fields of science and numerous heuristics approaches to solve them. From the literature, some former and some recent flow shop problems are illustrated in the research model where the objective is to identify recent distribution algorithms and respective formulation of hybrid algorithm(s) in order to minimize the makespan.

A multi-heuristic desirability ACS heuristic is proposed for the non-permutation (FSP) with objective to reduce makespan. The proposed MHD-ACS heuristic enhanced the quality of the upper bounds for the problem. The results of proposed heuristic were demonstrated and compared against other algorithms that were suitable for the problem. The Visual C++ was used for the coding of proposed heuristic and experiments were implemented on Intel Pentium 4 personal computer with 1.5GHz CPU [13].

A PFSP with makespan criteria is proposed a hybrid metaheuristic for the problem. The metaheuristic was designed by the combination of four constructive heuristics: the NEH heuristic, the CDS heuristic, Palmer's heuristic, and Gupta's heuristic along with the company of two metaheuristics: the GA and VNS. The designed algorithm was so-called as NEH_{VNS}, where the initial population was generated through constructive heuristics and improved via GA [14].

$$C(1,\pi_1) = p_1, \pi_1,$$

$$C(1,\pi_j) = C(1,\pi_{j-1}) + p_1, \pi_j, \quad j = 2,\ldots,n,$$

$$C(k,\pi_1) = C(k-1,\pi_1) + p_{k,\pi_1}, \quad k = 2,\ldots,m$$

$$C(k,\pi_j) = \max\left\{C(k,\pi_{j-1}), C(k-1,\pi_j) + p_{k,\pi_j}\right\}, \quad j = 2,\ldots,n;$$

A flow shop problem with blocking is proposed three hybrid algorithms based on Harmony search (HS) namely as (hHS), (hgHS) and (hmgHS). The primary goal of the research is to minimalize total flowtime of jobs. The continuous harmony vector was converted in job permutation through the implementation of LPV rule. The NEH_WPT heuristic was introduced to generate higher quality initial harmony memory of algorithm, and for the balancing of global and local exploitations, the global search based on HS and insert neighborhood-based local search were hybridized [15].

Four hybrid heuristic algorithms are recommended in view of the essential thought of Johnson algorithm for the two-stage assembly HFS scheduling problem. The impartial of scheduling was to decrease the completion time. The problem consists of HFS stage and an assembly stage where numerous set of parts designed for the products are manufactured in the HFS stage, and the complete products were assembled through various parts in the assembly stage. the final solution was obtained from the new lower bounds that were introduced in the heuristic algorithm [16].

A two-stage AFS problem is developed where the first stage consists 'm' parallel identical machines called as "fabrication stage" while the second stage is the assembly stage. A novel meta-heuristic GWO algorithm was developed, along with numerous heuristic procedures, dispatching rules, along with a lower bound were also developed. The objective of the scheduling was to reduce makespan. Also, a local search was included in the algorithm to enhance its performance. The execution of the lower bound was assessed by deviation of the LB (DVL) from the best solution of the algorithms [17].

A Competitive memetic algorithm (CMA) is presented for solving the (MODPFSP) with the makespan and total tardiness criteria. Two populations are employed to optimize two different objectives, and the competition

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among multiple search operators and the knowledge-based local search are performed. Besides, the interaction between the two populations is designed to improve the balance of the two objectives. The influence of the parameters on the performance of the CMA is investigated by using the Taguchi method of design-of-experiment. The CMA was coded in C language and run on PC with Intel i5-3470 processor and 8GB RAM under Windows 7 [12].

The anomalies of permutation flow shop scheduling problem is presented. Here, five types of anomalies have been reported with the objective of minimum makespan. Also, more seven types with minimal total flow time has been reported. Four new anomalies have also reported in no-wait non-permutation flow shop scheduling problems. As a conclusion, anomalies such as no-delay time, no-job waiting and no-machine idle time are reported as restrictions [18].

III. PROBLEM FORMULATION

The flow-shop scheduling environment consists of ‘n’ number of jobs, to be processed on ‘m’ number of machines, following the same sequence. The primary goal of flow-shop scheduling is to organize the jobs of the manufacturing system in such a way that maximum or optimized productivity can be achieved and hence, all the resources (man, machinery, finance) are utilized. In the past segments the broad review portrayed the different techniques to tackle the flow-shop problem under various objectives, parameters and constraints. In perspective of this, the most widely recognized issue is to optimize the make-span of the production system. Further, some issues like flow time, lateness, earliness, tardiness (or total weighted lateness, total weighted earliness and total weighted tardiness) with a (SDST) and due dates are recognized as the auxiliary issues.

There are ‘n’ number of jobs to be scheduled in a specific order in a flow-shop machine arrangement in order to optimize the objectives (Table 1). The jobs follow the constraints presented below:

(i) Set-up times are attached with each job

(ii) No-wait constraints.

(iii) Limited buffer and lot streaming constraints.

(iv)Release dates and delivery dates of jobs must be fulfilled.

(v) Multiple criteria’s are to be optimized.

Some of the research gaps are identified as:

(i) Usage of the heuristics strategies by blend and cross-functioning of execution measures of scheduling such as tardiness, lateness, due dates, minimization of makespan, considering sequence dependent set up times and backlogging have not been executed.

(ii) The retrospection of the research aims to utilize the conventional methods designed decades back such as GA, DE, TS, PSO, ACO, SA, and IA and so on, which confines the advancement of the recently framed strategies to illuminate the (FSS) problems. Further, the constraints like sequence dependent setups and backlogging have been seen in fewer studies with the non-conventional methods, consequently broadening the extent of more work to be executed in future.

(iii) There are less contextual investigations which are based on the real data analysis of the various parameters such as process time, flow time, lateness, earliness, tardiness and others, have been taken less into consideration related to (MFSP) problems and its constraints. The past research needs more practical plans, which can be returned, back to enhance the particular framework in the industry.

Table 1 Model problem of flow shop scheduling with 2 parts and 8 machines

Machines	M1	M2	M3	M4	M5	M6	M7	M8
Job1	J11	J12	J13	J14	J15	J16	J17	J18
Job2	J21	J22	J23	J24	J25	J26	J27	J28

TLBO is an optimization method, and is based on the teacher and student learning process. It is a naturally inspired population method, where class of learners will represent the population (Fig. 1 and Fig. 2). The best learner in the phase is selected as a teacher, as only a teacher is considered with best knowledge and then increments the knowledge level of the students known as learners, so as to obtain the good marks [19].

A hybrid meta-heuristic is predicated on probabilistic teaching-learning mechanism (mPTLM) to resolve no-wait FSS problem called as (NWFSSP). The meta-heuristic contains of four parts, i.e. (i) screening afore class, in which preliminary method that cumulates a modified (NEH) heuristic and the (OBL) was familiarized. (ii) Teaching phase, as the teacher to helps learners to more guaranteeing areas, the Gaussian distribution was employed. (iii) Learning phase, an incipient designates of communication with crossover was presented. (iv) Studying after class, for upgrading the local search capabilities an enhanced speed-up random insert local search based on (SA) was developed [20].

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```
% Select habitat
  habitat = pop(1);
  for i=2:nPop
      if pop(i).Cost < habitat.Cost
      habitat = pop(i);
      end
  end
     % Teacher Phase
      for i=1:nPop
    % Create Empty Solution
     newsol = empty_individual;

     % Habitat Factor
       HF = randi([1 2]);

       % Habitat (moving towards habitat)
        newsol.Position = pop(i).Position ...
         + rand(VarSize).*(habitat.Position - HF*Mean);
       end
```

Fig. 1 Teacher phase to proposed meta-heuristic in MATLAB

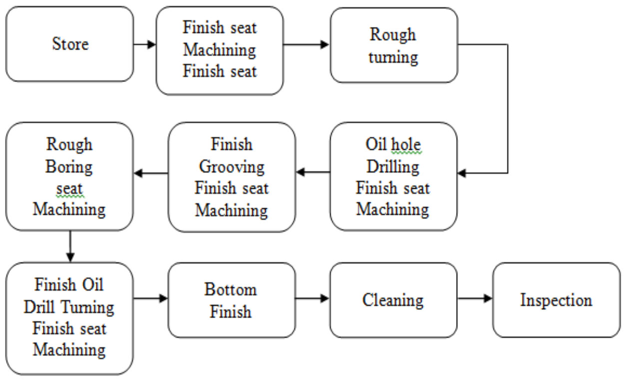

Fig. 2 The proposed process flow in a piston manufacturing industry

IV. IMPLEMENTATION OF PROPOSED META-HEURISTICS TO SCHEDULING

The migration phase includes immigration and emigration of the population and the mutation will preserve the diversity in the population. The teacher phase encourages the achieving the value near to the best solution. The heuristic will tend to minimize the function named as 'cost function value' as the number of iterations increases while using the different values of the variables each time for the successive iterations. The validation of the model is conducted by comparative analysis of actual results with computed values from MATLAB.

The input variables x(1) and x(2) follows the range between 1 and 15 which further impacts the optimization of the evaluated Cost function value. The variable x(1) = processing time of part 1 on machine 2 and x(2) = processing time of part 2 on machine 2. The constraints in the equation are x(1)>0, x(2)>0 and f<90. The mean of iterations for x(1) comes out to be 8.001 and that of x(2) is 9.515. The best cost function value is obtained is 36.596. Figure 4.3 refers the variation of the values of the function f=11x(1)+13x(2) ≤90 with the iterations taking place (Table 2). It is evident from the graph that as the number of iterations are increasing, the value of the function keeps optimizing. The maximum value 325.346 is at first iteration and there after optimized to 36.596 at the last. The minimum value of the function can be seen on the 20th iteration (Fig. 3). The dots in the graph represents, the value of function corresponding to the respective iteration. It is to be noted that the rate of optimization is not constant and varies differently between the successive iterations.

V. SIMULATION OF SEQUENCE-DEPENDENT SETUP TIME WITH BACKLOGGING

In scheduling, set-up time makes problem more unpredictable and comes to play when production changeover is required between the different jobs, taking different amount of time to set-up on the machine before starting the operation. The manufacturing of part 1 that is ring carrier piston is done on the eight different machines encountering different times on different machines.

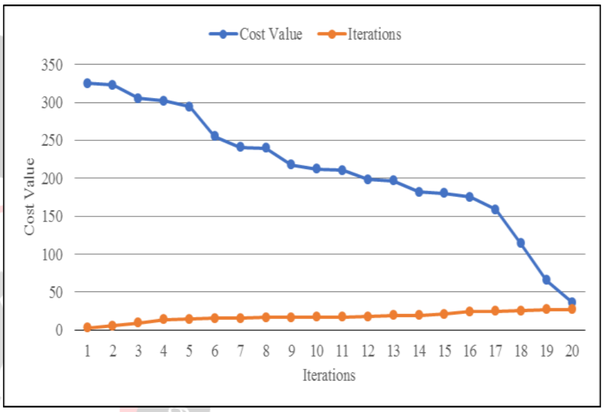

Fig. 3 Variation of function f=11x(1)+13 x(2) ≤90 corresponding to the number of iterations

Table 2 Evaluation and optimization of function 11x(1)+13x(2) ≤90 using proposed TLBO heuristic

x(1)	x(2)	Function Value
14.07855	13.114	325.346
14.28007	12.76366	323.0084
11.76362	13.53654	305.3749
10.18556	14.61727	302.0656
9.399992	14.68661	294.3258
8.637937	12.33325	255.3496
5.445005	13.90751	240.6927
6.53567	12.9314	240.0005
2.935237	14.25936	217.6593
3.029417	13.75474	212.1352
10.329	7.437852	210.3111
7.762087	8.699949	198.4823
13.00272	4.146792	196.9383
1.035964	13.11476	181.8875
9.57291	5.767285	180.2767
14.50491	1.218461	175.394
9.43871	4.223972	158.7374
4.298602	5.136468	114.0587
2.562796	2.884099	65.68404
1.221128	1.78182	36.59607
8.001	9.5158	

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Table 3 Depiction of the various times (in min) on various machines

Part 1	M1	M2	M3	M4	M5	M6	M7	M8
Set Up Time	2.5	1.5	2	3	2	2	2.5	3.5
Process Time	10	11	13	18	10	14	18	14
Backlog time	4	5	4.5	8	5	5.5	11	9
Cycle time	16.5	18	20	29.5	17.5	22	32	29
Reduced Cycle Time	14.765	15.083	14.090	10.375	10.198	14.049	12.229	12.486

Table 3 shows the set-up time, process time, backlog time, cycle time for the part on the various machines and the reduced cycle time, obtained by the implementation of TLBO heuristic. On machine M1 the set-up time is 2.5 min, backlog time is 4 min, cycle time is 16.5 min and reduced to 14.765 min by using the developed heuristic. On machine M2 the set-up time is 1.5 min, backlog time is 5 min, cycle time is 18 min and reduced to 15.083 min by using the developed heuristic. On machine M3 the set-up time is 2 min, backlog time is 4.5 min, cycle time is 20 min and reduced to 14.090 min by using the developed heuristic. On machine M4 the set-up time is 3 min, backlog time is 8 min, cycle time is 29.5 min and reduced to 10.375 min by using the developed heuristic. On machine M5 the set-up time is 2 min, backlog time is 5 min, cycle time is 17.5 min and reduced to 10.198 min by using the developed heuristic. On machine M6 the set-up time is 2 min, backlog time is 5.5 min, cycle time is 22 min and reduced to 14.049 min by using the developed heuristic. On machine M7 the set-up time is 2.5 min, backlog time is 11 min, cycle time is 32 min and reduced to 12.229 min by using the developed heuristic.

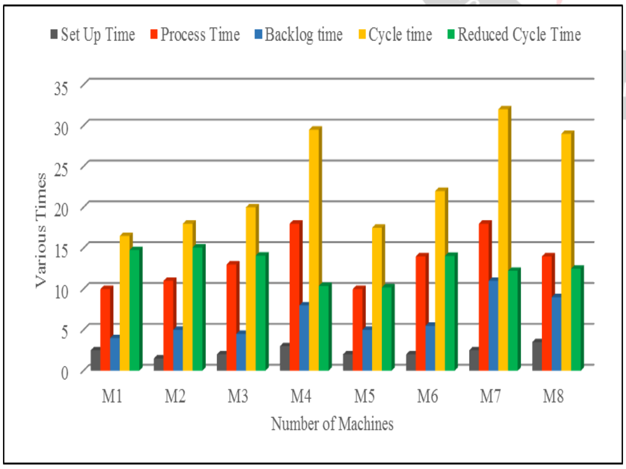

Fig. 4 Depiction of set up time, process time, backlog Time, cycle time and reduced cycle time

VI. VALIDATION OF MODEL

Validation is the process of certifying the produced results that if they are better than the actual data used or not. This procedure has favorable position to determine the quality of the results produced. The validation of the results produced by the proposed TLBO heuristic is compared with the actual data used to form the various functions.

Table 4 shows the actual data used to form the various objective functions and the results generated from the proposed heuristic.

Table 4 Depiction of actual process time and results by TLBO heuristic

Machines	M1	M2	M3	M4	M5	M6	M7	M8
Actual time	10	11	13	18	10	14	18	14
Results obtained from TLBO heuristic	7.042	8.001	7.674	9.572	6.706	8.967	8.706	8.943

Figure 5 depicts the comparison between the total processing time and optimized processing time of part 1 and part 2 by the results obtained from the implementation of developed TLBO heuristic. The most optimized machine time for part 1 and part 2 is on machine M7 where 22.793 min are optimized from the combined processing time of 39 min. The least optimized time is found on machine M2 where the combined process time of 24 min is optimized by 6.484 min. The rest of the machines are optimized within the range of 6.484 min to 22.793 min. The green bars displaying the optimized values of process time for part 1 and 2 while the red indicates the actual process time of part 1 and 2 (Fig. 5).

It reduces the value of cycle time of part 1 from 29 min to 12.486 min and that of part 2 from 35.5 min to 13.716 min. The value of the variable used by proposed heuristic in the analysis for part 1 ranges from 1.867 to 23.151 and for part 2 ranges from 1.672 to 23.723. The minimum and maximum value of function is 335.855 and 1323.746, respectively.

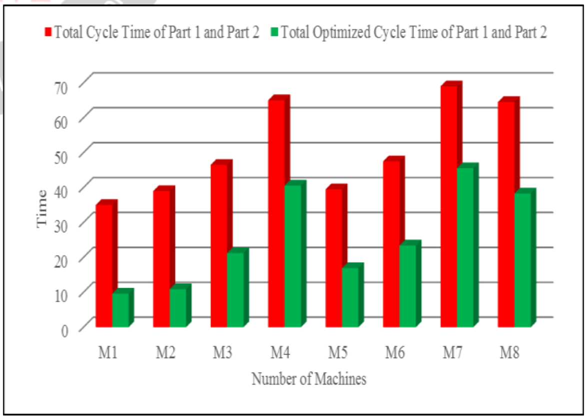

Fig. 5 Graphical presentation of total cycle time and total optimized cycle time for part 1 and part 2 on various machines

VII. CONCLUSION AND FUTURE SCOPE OF WORK

In the present research, a new hybrid heuristic model is proposed depending on search algorithms for production scheduling and also developed a programming code in MATLAB to solve the multi-objective scheduling problem. The proposed algorithm can be used for analyzing

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scheduling problems up to eight machines. Otherwise, there are some cases to be considered as mentioned. The process time and the cycle time have been minimized by means of the proposed TLBO heuristic, and the optimized results contribute the variation in the objective function. The respective function will go on decreasing with increase in the number of iterations. The successive iterations utilize the different value of the variables, hence maintaining the diversity in the set of solutions. To make the system more realistic, the Sequence Dependent Setup Time (SDST) and backlogging time was configured with multi-objective flow shop scheduling problem. This is proficient as various choices are regularly required in this unique and focused encompassing. Remembering these clashing conditions, the proposed heuristic tends to locate the powerful arrangements undertaking at that point concerned conditions. The actual data, i.e., process time and cycle time are optimized using the proposed TLBO heuristic. For part 1, the processing time on the eight machines has been optimized ranging between 2.95 to 9.29 minutes and optimized process time of part 2 ranges between 3.48 to 13.68 minutes. The optimized cycle time of part 1 ranges between 1.73 to 19.71 minutes and optimized cycle time of part 2 ranges between 7.86 to 25.82 minutes. The population size is 20, number of variables is 2, number of iterations is 20. Therefore, the reduced time refers the effectiveness of the proposed hybrid heuristic algorithm and hence, it makes the system more reliable.

The proposed work recommend is to select effective heuristics for the specific problems and design or develop novel hybrid methods or approaches through their combinations. The present study uses hybrid BBO-TLBO heuristic to optimize the dual objectives of process time and cycle time. The present study would recommend to the change the selected values of various constants such as lower and upper bound limits; population rates; number of variables and number of iterations and so on according to the requirement of data because these changes might modify the quality of the optimized values. Further, it is also recommended, if possible, to choose different values of the above constants according to the objective function under consideration.

The proposed research work presented a design of novel hybrid heuristic for multi-objective flow shop scheduling in order to minimize dual objectives, the process time and the cycle time with SDST and backlogging constraints. Hence it is very naive and is open to the any type of explorations which expands the horizon of the proposed TLBO heuristic. The proposed work only focused to minimize two objectives, the process time and cycle time. Whereas, there are number of other objectives such as total weighted squared tardiness, earliness, make-span, total weighted squared earliness and number of tardy jobs, delay time, completion time and so on which can be solved using the proposed hybrid heuristic. These objectives can be solved individually or taken multiple at time.

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