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Retraction

Retracted: An Effective Hybrid Multiobjective Flexible Job Shop Scheduling Problem Based on Improved Genetic Algorithm

Scientific Programming

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] J. Fang, "An Effective Hybrid Multiobjective Flexible Job Shop Scheduling Problem Based on Improved Genetic Algorithm," *Scientific Programming*, vol. 2022, Article ID 2120944, 10 pages, 2022.

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Research Article

An Effective Hybrid Multiobjective Flexible Job Shop Scheduling Problem Based on Improved Genetic Algorithm

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Multiobjective Flexible Job Shop Scheduling Problem (MO-FJSP) is a scheduling problem used in manufacturing sectors to use energy efficiently and thriftily. The scheduling problem aims to increase productivity and reduce energy consumption via a mathematical model. With this paper, an effective genetic algorithm is proposed for MO-FJSP based on maximum completion time, total machine load, and bottleneck machine load. The solution method utilizes a hybrid multiobjective genetic algorithm. A combination of global selection and fast selection is used for initialization and obtaining a uniformly distributed initial population. The cross-variance operator is adaptively improved to enhance the searching in the population. Following that an elite retention mechanism is designed to address the possible limitations of the elite strategy in maintaining population diversity. As a result, an improved harmonic search algorithm is introduced to improve the quality of individuals in the elite pool. The proposed hybrid method is implemented in MATLAB R2018a. Tests were conducted using the benchmark Kacem test set, the BR data data set, and with the actual production cases. The algorithm succeeded in achieving 13 nondominated solutions in the initial 20 runs. Moreover, the method obtains the optimal value criterion for the solution accuracy factor. As a whole, results of the evaluation testify that the proposed method can be used to solve the MO-FJSP with high accuracy and fast convergence. The method also provides feasible and effective scheduling solutions for the decision-makers in actual production. Based on the promising results obtained, it is deduced that the method has a wide applicability range particularly in manufacturing sector.

1. Introduction

With every passing day, awareness about environmental issues and lack of energy sources, new ways are searched out to efficiently use energy in the manufacturing of machines and mechanical units [1]. For energy-efficient production processes, job-shop scheduling is been suggested by the researchers [2–4]. The traditional approaches of Job Shop Problems (JSP) [5] were all about minimizing the makespan. MO-FJSP on the other hand deals with the selection of operations together with influencing the sequence of operations [1]. Various scheduling approaches have also been proposed for productive utilization of resources. For instance, Shopfloor production scheduling is an effective scheduling method that can be used for effective and optimization as well. The rational scheduling method for the production plans in the manufacturing process is another useful approach. The method plays a key role in improving the productivity, resource utilization, and cost reduction of enterprises. Nevertheless, the Flexible Job Shop Problem (FJSP) introduces new decision content into the traditional job-scheduling problem. The additional content supported in FJSP includes the solution of two subproblems. One of the subproblems is to select the appropriate machine for each process. The second subproblem is to determine the start and end processing time of the processes, a more complex NP-hard problem [6].

After nearly 30 years of exploration, the research of FJSP has achieved fruitful results. Until now, different meta-heuristic algorithms have been successfully applied in practical scheduling problems. For instance, the genetic algorithm (GA) [7], particle swarm algorithm [8], forbidden search algorithm [9], and simulated annealing algorithm [10] are some of the extensively used algorithms. With advancement in research, the multiobjective flexible job shop scheduling (MO-FJSP) appeared to be more in line with the production reality. Hence, MO-FJSP has become a pressing problem to be solved. Since last decade, new algorithms have been proposed to offer more options and to conveniently solve MO-FJSP. Meng, Champion et al. [11] proposed a hybrid artificial bee colony algorithm. The algorithm utilizes different search methods in three distinct stages: hiring bee, following bee, and detecting bee. In addition, a forbidden search algorithm is introduced to improve the probability of obtaining the optimal solution. Wei et al. [12] proposed an improved artificial immunity algorithm. The algorithm makes the use of Metropolis criterion of simulated annealing algorithm to speed up the search efficiency while ensuring the population diversity. Ju et al. [13] proposed an improved whale swarm algorithm. To expand the search range of individual whales, the algorithm follows a cooperative search mechanism. The global and local search-ability of the population is improved by introducing the variable neighborhood search (VNS) algorithm. Pan et al. [14] suggested a variable neighborhood weed optimization algorithm to establish a scheduling model with De-jong learning effect. Besides, a variable neighborhood search algorithm is introduced in the most-recent iteration with three neighborhood structures: N1, N2, and N3. Effectiveness of the algorithm was verified through experiments. Recent studies suggest that a hybrid algorithm suffers from fewer shortcomings than a single algorithm. As a hybrid algorithm combines the characteristics of two or more algorithms, therefore, better adaptability and robustness is guaranteed. It is why current trends in the literature of job shop problem are to study and solve the MOJSP.

In this paper, a hybrid multiobjective genetic algorithm (our method) is proposed to solve the MO-FJSP. The method is based on the nondominated ranking genetic algorithm by introducing the harmony search (HS). Numerical experiments are demonstrated to assess feasibility, effectiveness, and practicality of the proposed algorithm. The promising results obtained testify superiority of the proposed method.

Rest of the paper is arranged as followed. Related literature is presented in Section 2. The proposed method is discussed in Section 3. Experimental analysis is discussed in Section 5. Finally, conclusion and future strategy is presented in Section 6.

2. Related Work

Most of the national- and international-level research on the single-objective FJSP problem mainly targets the maximum workpiece completion time. Key motive of the research works is to shrink the maximum workpiece completion time. For the purpose, a GA is proposed by Wang et al. [15] to generate a high-performance initialization population. The algorithm employs a strategy of mixing two machine assignment rules and three process sequencing rules. The two-population algorithm of Nawaz Ripon [16] works on picking two subpopulations to optimize two subproblems, machine allocation, and process sequencing sequences. Similarly, Chen et al. [17] designed a machine-selection method for the effective solution of machine load balancing. The algorithm follows three selection strategies (global, local, and random) to generate solution. Huang et al. [18] defined a new transformation method based on differential evolutionary (DE) algorithm for solving FJSP. To improve search performance, the method combines DE with critical path based local search technique. In a similar research work [19], the critical path local search strategy is used besides the shuffled frog leading algorithm (SFLA). The method promises for the improved convergence performance of SFLA. In Osaba et al.'s study [20], a discrete harmony search (DHS) algorithm is suggested to encode the machine selection and process ranking subproblems. The designed algorithm transforms a continuous harmonic vector into two discrete vectors. The strategy of VNS is proposed in the literature [21] to solve the single-objective FJSP.

To summarize, there are two general approaches to multiobjective optimization problems: the a priori method and the posteriori method. Both of the methods deal with resolving possible conflicts involved in multiple objectives. The a priori method generally uses the experience to form a single objective by linear weighting of multiple objectives. However, fewer solutions can be obtained using this type of method. The method fails to reflect the trade-off between different objectives [3]. Moreover, it is difficult to precisely determine weights of each objective. Enough experience is required to solve optimization problems; however, the true Pareto front is nonconvex [3] in the aggregation-based approach. From the in-depth analysis of the literature, it is clear the priori methods are basically used to transform the multiobjective into a single objective by weighting. Although a posteriori method may offer multiple solutions, the method lacks problem-based local search. Hence, the obtained solutions are somehow unreasonable and cannot guarantee a set of optimal solutions. It is why such algorithms do not effectively balance the global search and local development [3].

Details of some of the standard approaches in the realm of job shop problem are presented in Table 1.

3. Multiflexible Job Shop Scheduling Problem Model

A multi-FJSP is the extension of the tradition JSP which allows multioperations to be processed by a set of machines. The problem is about assigning an operation to a machine by ordering the operations on the machines. Key focus of the MJSP is to attain minimum makespan of all the operations. It is a sort of NP-hard problem to effectively deal the two subproblems: assignment and the scheduling.

3.1. Problem Description. In the actual flexible shop production, there exist parallel machine flexibility, worker flexibility and process flexibility at the same time. This paper proposed a novel approach for MO-FJSP that is summarized in the following steps. (1) Multiple workpieces are processed on multiple machines by multiple workers belonging to each

Table 1: Some of standard method methods in the literature of MO-FJSP.

Author (s)	Title	Algorithm	Purpose
Hurink and Knust [21]	Tabu search algorithms for job-shop problems with a single transport robot	Simulated annealing scheduling	To minimize both total completion time and total tardiness.
Zhang et al. [22]	Energy-efficient permutation flow shop scheduling problem using a hybrid multiobjective backtracking search algorithm	Hybrid multiobjective backtracking search	To minimize energy consumption and makespan
Dei et al. [2]	Solving flexible job shop scheduling problems with transportation time based on improved genetic algorithm	Transportation time based genetic algorithm	To minimize the maximum completion time and to optimally get the active scheduling policy.
Zhang et al. [23]	Energy-efficient scheduling for a flexible flow shop using an improved genetic-simulated annealing algorithm	Energy-efficient mathematical model	To ensure energy-efficient flow shop scheduling via the use of mathematical model.
Giglio et al. [24]	Mathematical modeling and evolutionary generation of rule sets for energy-efficient flexible job shops	Gene expression programming (eGEP) algorithm	To easily obtain optimization by generating energy-oriented heuristic rules
Rossi [25]	Integrated lot sizing and energy-efficient job shop scheduling problem in manufacturing/remanufacturing systems	Relax-and-fix heuristic	To decrease total weighted tardiness and energy consumption in a job shop scheduling problem
Karumi et al. [26]	Flexible job shop scheduling with sequence-dependent setup and transportation times by ant colony with reinforced pheromone relationships	Intelligent swarm approach based on the disjunctive graph model	To ensure effective scheduling with resource separable setup times

skill level. As the processes of each workpiece belong to different priorities; therefore, processing is carried out to the defined priority constraints, supposing no sequential constraints for the processes of same priority. Figure 1 shows the selection of machines and workers. There are four machines, five workers of three levels of priority. A workpiece is assigned to a machine that can be completed by five processes of three priority levels. The scheduling scheme requires assigning one machine and one worker to each process, giving adequate time to start the processing.

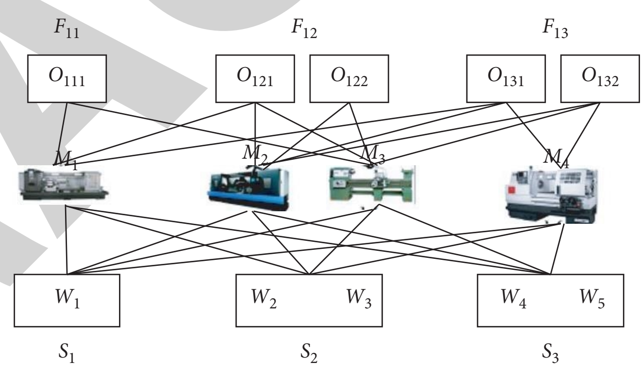

Figure 1: Example of a multiflexible job shop scheduling problem.

3.2. Symbol Definition. The notation used in the model is defined as follows:

n indicates the total number of workpieces

m indicates the total number of machines

u indicates the total number of worker skill levels

i, e are the subscripts of the workpiece, where j_i, j_e are the ith and eth workpieces to be machined

L_i, L_e are the number of priority levels contained in the artifacts, j_i, j_e, respectively

j, f are the priority subscripts, whereas F_{if}, F_{ij-1}, F_{iL_i} are the priorities of the jth, $j-1$th (i.e., the previous layer of the jth layer) and last layers of artifact j_i; F_{ef} is the priority of the fth layer of the artifact

k_{ij}, k_{ij-1}, k_{iL_i}, k_{ef} is the number of processes competing with priority k_{ij}, k_{ij-1}, k_{iL_i}, k_{ef}

k, q, g are the process subscripts where O_{ijk} and O_{ijg} are the kth and gth processes with priority k_{ij}, O_{iLi^k} is the kth process in priority

F_{iL_i} is the qth process in priority O_{ij-1_q}

K_{ij-1} is the gth process in priority; O_{efg}

s is the subscript of the worker's skill level where S_s is the sth skill level

N_s is the total number of workers at skill level S_s

V is the worker subscript, and E_{su} is the vth worker at skill level K

$C_{\max}$ is the maximum completion time

C_{mean} is the average completion time

E is the total energy consumption

3.3. Model Establishment. The mathematical model of multiflexible job shop scheduling problem is given as follows:

$$\min C_{\max} = \max_{1\le i\le n}\left(C_i\right) = \max_{1\le i\le n}\left(\max_{1\le k\le K_{il_i}}\left(C_{iL_ik}\right)\right), \tag{1}$$

$$\min E = \sum_{p=1}^{m}\sum_{i=1}^{n}\sum_{j=1}^{L_i}\sum_{k=1}^{K_{ij}}\sum_{s=1}^{n}\sum_{v=1}^{N_s} x_{ijkp}x_{ijksv}P_p t_{ijkps}, \tag{2}$$

$$\min C_{\text{mean}} = \frac{\sum_{i=1}^{n} C_i}{n} = \frac{\sum_{i=1}^{n} \max_{1\le k\le K_{iLi}}\left(C_{iL_ik}\right)}{n}. \tag{3}$$

Equations (1) to (3) are the optimization objectives: (1) represents the minimized maximum completion time; (2) represents the minimized total energy consumption; and (3) represents the minimized average completion time. The model has the following constraints.

3.3.1. Processing Resource Constraints

$$\sum_{p=1}^{m} x_{ijkp} = 1, \forall i, j\colon i = 1, 2, \cdots, n;\ j = 1, 2, \cdots, L_i, \tag{4}$$

$$\sum_{s=1}^{n}\sum_{v=1}^{N_s} x_{ijksv} = 1, \forall i, j\colon i = 1, 2, \cdots, n;\ j = 1, 2, \cdots, L_i, \tag{5}$$

Equations (4) and (5) ensure that only one worker and one machine are selected for a given process at a time.

$$\begin{aligned}
&\sum_{p=1}^{m}\left(sT_{efg} - eT_{ijk}\right)x_{efgsv}\\
&\quad x_{ijksv} \ge 0 \vee \sum_{p=1}^{m}\left(sT_{ijk} - eT\right)x_{svefg}\\
&\quad x_{ijksv} \ge 0, \forall i, j, k, e, f, g, s, v\colon i, e = 1, 2, \cdots, n;\ s = 1n2, \cdots, u;\\
&\quad v = 1, 2, \cdots, N_s;\ j = 1, 2, \cdots, L_i;\ f = 1, 2, \cdots, L_e k = 1, 2, \cdots, K_{ij};\ g = 1, 2, \cdots, K_{ef},
\end{aligned} \tag{6}$$

$$\begin{aligned}
&\sum_{s=1}^{n}\sum_{v=1}^{N_f}\left(sT_{efg} - eT_{ijk}\right)x_{ef_{fp}}\\
&\quad x_{ijkp} \ge 0 \vee \sum_{s=1}^{n}\sum_{v=1}^{N_n}\left(sT_{ijk} - eT_{ef_g}\right)x_{efgp}\\
&\quad x_{ijkp} \ge 0, \forall i, j, k, e, f, g, pi, e = 1, 2, \cdots, n;\ p = 1, 2, \cdots, m;\ j = 1, 2, \cdots, L_i\\
&\quad f = 12, \cdots, L_e;\ k = 1, 2, \cdots, K_{ij};\ g = 1, 2, \cdots, K_{ef},
\end{aligned} \tag{7}$$

Equation (6) and (7) ensure that one worker or one machine can be involved in processing only one process at the same time.

3.3.2. Processing Time Constraint

$$\begin{aligned}
&eT_{ijk} - sT_{ijk} = \sum_{p=0}^{m}\sum_{s=1}^{n}\sum_{v=1\ tijkpsv}^{N_s} x_{ijk}x_{ijksv},\\
&\quad\forall i, j, k\colon i = 1, 2, \cdots n;\ j = 1, 2, \cdots, L_i;\ k = 1, 2, \cdots, K_{ij}.
\end{aligned} \tag{8}$$

Equation (8) represents the relationship between process start time and completion time.

(3) Workpiece completeness constraint and transportation time constraint

$$\begin{aligned}
&sT_{ief} - eT_{ijk} - \sum_{p=0}^{m}\sum_{r=0}^{m} x_{ijkp}x_{ief_r}\\
&\text{trans}\, T_{pr} \ge 0, \forall i, j, e, k, f;\ i = 1, 2, \cdots, n;\ j = 1, 2, \cdots,\\
&L_i;\ e = 1, 2, \cdots, L_i;\ k = 1, 2, \cdots <, \text{ and } > K_{ij};\ f = 1, 2, \cdots, K_{ie}.
\end{aligned} \tag{9}$$

Equation (9) represents the transport time required for a workpiece to be processed in only one process at the same moment while ensuring its transfer from one machine to another.

3.3.3. Priority Constraint

$$\begin{aligned}
&sT_{ijk} \ge \max_{1\le q\le K_{ij}-1}\left(eT_{ij-1q}\right),\\
&\forall i, j;\ i = 1, 2, \cdots, n;\ j = 1, 2, \cdots L_i.
\end{aligned} \tag{10}$$

Equation (10) ensures that the workpiece with the highest priority is machined first.

3.4. Code. A four-chromosome integer code can be used for the proposed MO-FJSP. One of the chromosome codes the machine and the other chromosome codes the worker assignment, as shown in Figure 2. The process O122 is selected and assigned to the machine number three and worker number three. It should be noted that the worker serial number is uniform for all workers, for example, workers W_{11}, W_{12} and W_{21}, W_{22} in two skill levels will be renumbered as W_1, W_2, W_3, W_4.

Two chromosomes encode process ordering is followed in the algorithm. From the two chromosomes, the first chromosome has genes that are both subscripts of the artifacts. The second chromosome has genes that are distorted integers from 1 to the total number of processes, as shown in

	O_{111}	O_{121}	O_{122}	O_{131}	O_{132}	O_{211}	O_{212}	O_{221}	O_{222}
Mechanical selection	1	2	3	1	4	2	1	2	4
Worker assignment	1	3	3	2	4	3	4	1	2

Figure 2: Machine and worker coding.

Figure 3. In Figure 3, the same artifacts in the chromosomes of process order 1 are divided into priority levels by sequential constraints, as shown in Figure 4. Each priority level in Figure 4 contains multiple processes. The processes in each priority level are sorted by the integer size of the corresponding position of the chromosome of Process Order 2 (see Figure 3). The sorting process is shown in Figure 5. The scheduling schemes obtained from the four-chromosome coding and decoding meets the constraints of the model.

For the characteristics of the problem and heuristic encoding, a variational crossover operator is proposed. Detail of the process is given as followed.

3.4.1. Variation Operator. To carry out the evolutionary process, multiobjective algorithms rely on the use of variation operators. In the proposed method, a single-point mutation of one to multiple positions is used for machine-selected and worker-assigned chromosomes. The position swap technique is followed for chromosomes of process order 1. Four types of variable neighborhood search are adopted for the chromosome equal to the probability of process ordering 2. The neighborhood search variables followed in the algorithm are the swap, insertion, reversal of reverse order, and the disruption of swap [11].

3.4.2. Crossover Arithmetic. The crossover arithmetic operator is used to linearly combines the two parent chromosomes. In the proposed method, individuals of the parents were paired into different pairs. The pairs include selection of gene positions, exchange of genes on the machine-selected and worker-assigned chromosomes in the parent individuals. Furthermore, the pairs also include comparison of the artifact numbers of the chromosomes of process order 1 in the parent individuals and the selection of genes at other positions. The purpose of the paring is to complement the parents so that the total number of artifact numbers on the chromosomes remained the same after the exchange of genes. For the chromosomes of process order 2, equal probability position-based crossover (PBX) and linear order crossover (LOX) were used [11].

4. Optimization Algorithm

Optimization algorithm is the problem of discovering a set of inputs to an objective function to maximum or minimum the function evaluation. Some state-of-the-arts optimization algorithms are discussed in the following subsections.

4.1. Invasive Tumor Growth Optimization Algorithm. Invasive tumor growth optimization (ITGO) is a novel population intelligent optimization algorithm proposed by Wei et al. [12] in 2015. The algorithm is significantly more advantageous than the intelligent algorithms, continuous optimization problems [12], data clustering problems [13], and cloud computing task scheduling problems [14]. ITGO works on the simulation of tumor cells. The algorithm analogizes the solution of the problem of growing cells (Pcell), invading cells (Icell), dormant cells (Qcell), dead cells (Dcell), and so on. Moreover, the fitness value is assimilated to the nutrient concentration. In the algorithm, the cells will move toward the direction of higher nutrient concentration. Among the cells, the Icell is the most active one that takes up part of the search task and then all the tasks by jumping out of the local optimal solution. The Pcell takes up most of the search work, whereas the Qcell slowly executes the search strategy. The Dcell is formed by the decay of the dormant cells and releases the occupied computational resources once it completes its task. The various cells can be transformed into each other.

4.2. NSGA-II Algorithm. The nondominated Sorting Genetic Algorithm (NSGA) II makes the use of fast nondominated sorting (FNDS) method to classify individuals in the population into different nondominated ranks (NDR). The algorithm calculates the crowding distance between individuals NDRs. Next, individual filtering is performed based on NDR and crowding distance. In the multiobjective optimization problem with three or more objectives, the ranking method based on crowding distance is not obvious. To resolve the issue, Huang et al. [27, 28] suggested the reference-point-based method (RPBM) and NSGAIII. However, NSGAIII encounters the problem of excessive number of solutions while dealing with high dispersion problems. The problem of excessive number of solutions in the optimal NDR may be resolved at the later stage that will adversely affect further screening.

4.3. Multiobjective Invasive Tumor Growth Optimization Algorithm. In this paper, we propose a multiobjective invasive tumor growth optimization algorithm. Schematic of the algorithm is shown in Figure 6. The MOITGO is utilized along with the FNDS and RPBM-based selection methods and NSGAIII. The RPBM reference points are generated using Das and Dennis's method [29]. In MOITGO, "division" refers to the replication of one original cell into another cell type while "transformation" refers to the change of cell type. A Pcell that remains unchanged during the growth

Operation sort 1	7	5	3	2	6	8	1	9	4
	O_{111}	O_{121}	O_{122}	O_{131}	O_{132}	O_{211}	O_{212}	O_{221}	O_{222}
Operation sort 2	1	2	2	1	2	1	1	2	1

Figure 3: Work sequence code.

Prioritization	F_{11}	F_{21}	F_{21}	F_{12}	F_{22}	F_{12}	F_{13}	F_{22}	F_{13}

Figure 4: Priority coding.

Processing sequence	O_{111}	O_{121}	O_{122}	O_{131}	O_{132}	O_{211}	O_{212}	O_{221}	O_{222}

Figure 5: Machining sequence corresponding to the work sequence code.

cycle may fall into the local optimal solution. Thus allowing Pcell to divide into an Icell and prevents the algorithm from falling into the solution. In the proposed method, the cell growth and invasion methods are redesigned according to the discrete characteristics of MO-FJSP, as shown in Figures 7 and 8, respectively.

5. Experiments and Analysis of Results

In order to verify the feasibility, effectiveness, and practicality of the proposed MO-FJSP solution method, standard algorithms were selected for the evaluation. The actual production cases for testing were derived from the widely acceptable algorithms including the Kacem test set [14] (8×8 (P-FJSP), 10×10 (T-FJSP), 15×10 (T-FJSP)), the BRdata data set [27] (MK01-MK10), and the BRdata data set [27] (MK01-MK10). The algorithm is programmed using MATLAB R2018a. For the implementation and evaluation a laptop, with CPU Intel i7-4558U running at 2.80 GHz, having 4 GB of RAM, and Windows 7 operating system, was used. The test objective functions were performed according to equations (1) to (3) presented in Section 1.2. The parameters set used in the proposed method includes total number of iterations, population size, crossover probability range (0.4, 0.8), variation probability range (0.01, 0.2), number of iterations of the harmonic search algorithm, and probability of fine-tuning the harmonic memory bank.

5.1. Experimental Setup. In order to systematically assess the proposed method from different perspectives, the following experiments were performed.

5.1.1. Experiment-1. The first experiment was conducted to compare the proposed method with the noninferior solutions of NSGA-II. After each 20 runs, results of the algorithms were compared in terms of maximum completion time and minimum under the BRdata data set. The results obtained are shown in Table 2.

As shown in Table 2, both the algorithms achieved promising results. Performance of the methods (the proposed and NSGA-II) are better than the Brandimarte's method. Unlike our proposed method, quality of noninferior solutions obtained by NSGA-II decreases with the increase of the problem size. For the problem MK02–MK10, the noninferior solutions obtained by our method are better than those obtained by NSGA-II. Moreover, the results of 20 operations do not fluctuate considerably. This shows good stability in the quality of solutions. The iterative process and the distribution of noninferior solutions for a certain runs of the MK01 problem are compared.

5.1.2. Experiment-2. Under the Kacem test set results, the proposed method is compared with the hybrid artificial bee colony algorithm (ABC + TS). The ABC algorithm proposed by Champion Meng is considered to one of the state-of-the-art algorithm in the literature. Moreover, the results were also compared with the other cutting-edge algorithms namely the variable neighborhood weed optimization algorithm (IWO + VNS) proposed by Lei Cao, and the hybrid algorithm of local approximation and control genetic algorithm (AL + CGA) proposed by Kacem. Outcomes of the comparison are shown in Table 3.

It is clear from Table 3, that IWO + VNS obtained more noninferior solutions for the Kacem 8×8 problem. However, none of the algorithms reached the optimal value for the rest of the problems. Unlike others, the method proposed in this paper obtained the optimal value criterion in terms of solution accuracy. The number of nondominated solutions obtained by the proposed method is also not inferior to the other algorithms.

5.1.3. Experiment-3. In order to robustly assess the practicality of our method, it is evaluated by solving practical problems. This experiment intends to measure the judge the algorithm in scheduling case of an automotive wiring harness manufacturing enterprise. The production process of an automotive wire harness includes wire laying,

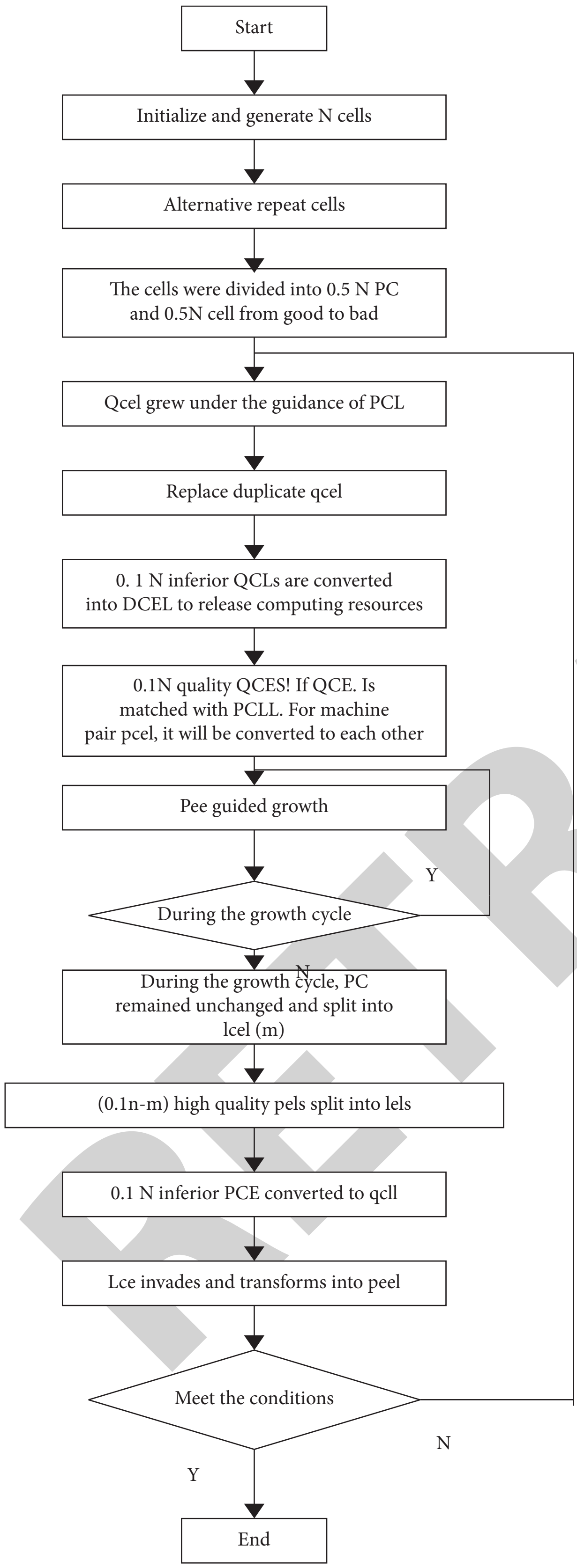

Figure 6: Results of multiobjective invasive tumor growth optimization algorithm.

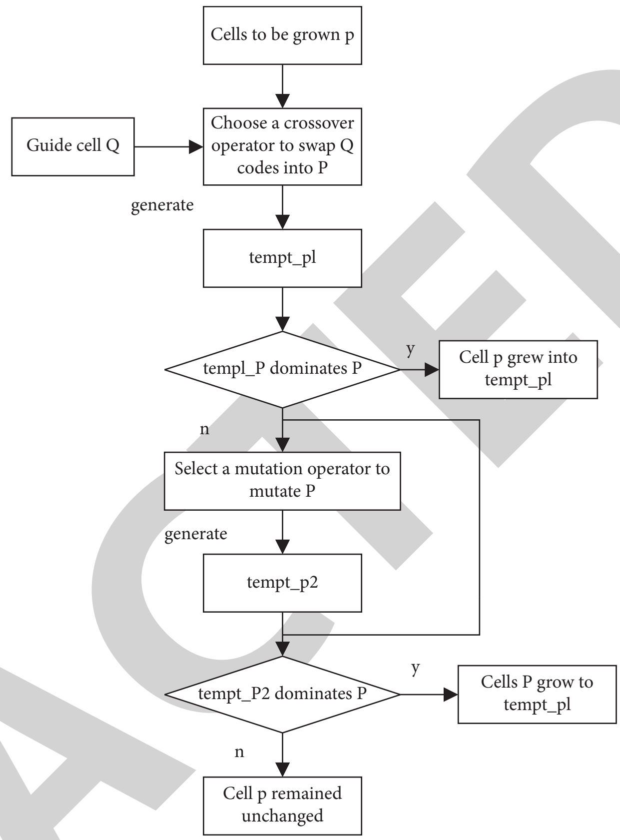

Figure 7: Cell growth under the guidane of another cell.

crimping, internal linking, subassembly and final assembly, and so on. Taking a wire harness with 6 branches as an example, the 6 subassembly branches in the corresponding process were treated to be 6 workpieces. Each of the workpiece J_1, J_3, J_4, contains 4 processes with process sequence number: 1, 2, 3 and 4. The workpiece J_2, J_5, J_6 contains 3 processes with process sequence numbers 1, 2, and 4. The output of the product was deemed to be 50 pieces. The production data of wire harness products are shown in Table 4.

As presented in the actual production data in Table 4, the NSGA-II and our proposed method were used for the scheduling solution. The results were also compared with the traditional manual scheduling method. Outcomes of the scheduling methods in solving the actual problem are compared and shown in Table 5.

From the facts presented in Table 5, it is clear that the manual scheduling method relies more on human than the two intelligent scheduling algorithms. As the scheduling and production processing time is longer, therefore, the scheduling effect is poorer. Our proposed method has obvious advantages over the NSGA-II in terms of production processing time and the number of noninferior solutions despite the fact that the scheduling time was slightly longer. The automotive wiring harness company can select the appropriate solution from the obtained noninferior solutions to guide the production.

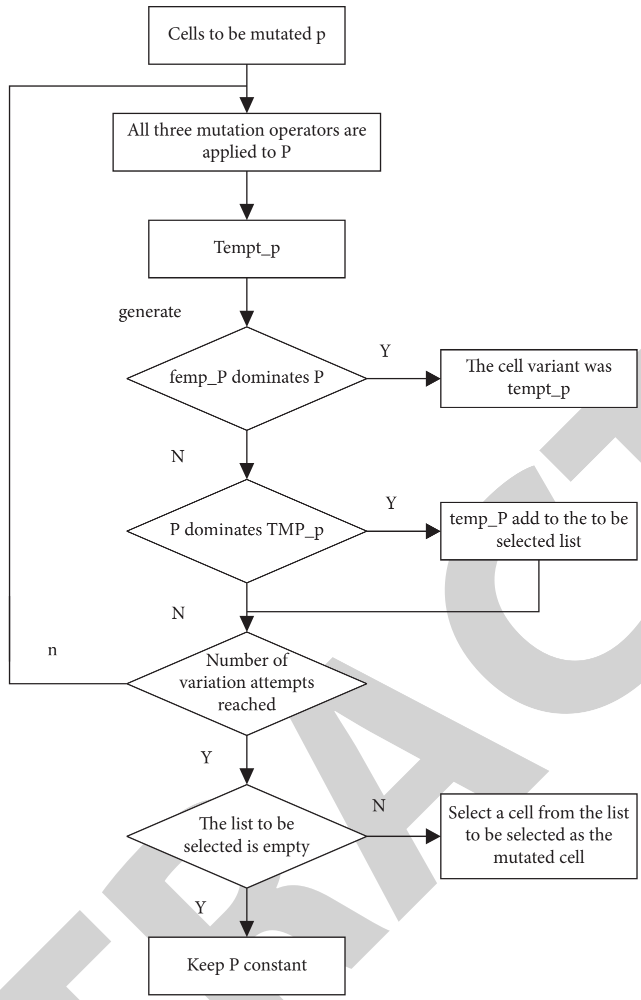

Figure 8: The process of cells invasion.

Table 2: Comparison of our method and NSGA-II results.

Problem type	$n \times m$	T	Brandimarte method (min)			NSGA-II (min)			Our method (min)		
MKO1	10×6	55	f_{1l}	f_{2l}	f_{3l}	f_{1l}	f_{2l}	f_{3l}	f_{1l}	f_{2l}	f_{3l}
MKO2	10×6	58	42	N/A	N/A	36	167	36	36	167	36
MKO3	15×8	150	32	N/A	N/A	30	142	30	27	147	27
MKO4	15×4	90	211	N/A	N/A	213	844	212	204	850	204
MKO5	10×15	106	81	N/A	N/A	67	357	65	63	360	60
MKO6	20×5	150	186	N/A	N/A	185	676	185	174	683	174
MKO7	20×20	100	86	N/A	N/A	70	407	59	66	398	62
MKO8	20×10	225	157	N/A	N/A	161	600	161	148	673	144

In summary, the method proposed in this paper has high solution accuracy and fast convergence. The algorithm carries a commendable global and local search capability. The method achieves optimal results on the selected benchmark instances of different scales and actual production cases. Moreover, the algorithm has better adaptability and robustness than the other contemporary algorithms. From the promising results obtained in the evaluation, it is proved that the proposed method is feasible and effective for solving MO-FJSP. Keeping in view

Table 3: Comparison of the operation results of each algorithm.

Problem type	T	Solution number	AL + CGA (min)		ABC + TS (min)		IWO + VNS (min)		Our method (min)	
			f_{1l}	f_{2l}	f_{1l}	f_{2l}	f_{1l}	f_{2l}	f_{1l}	f_{2l}
8×8		1	15	79	14	77	15	75	14	72
		2	16	75	15	78	16	73	14	73
	27	3	15	75	17	78			15	70
		4					17	76		
		5					18	75		
10×10		1	7	45	7	41	9	41	7	42
		2			7	41	8	42	7	42
	30	3			8	43	7	42	8	41
		1	11	91	11	90	11	91	11	91
15×10	56	2			12	91	11	93	10	94
		3			12	96			12	94

Table 4: Wire harness product processing production data.

Operation sequence	Process name	Optional equipment	Corresponding processing time/(min time)
1	Offline	M_1, M_2	0.03,0.05
2	Crimping	M_3, M_4	0.02,0.03
3	Inline	M_5, M_6	0.06,0.08
4	REPACK	M_7, M_8	0.04,0.05

Table 5: Comparison of the results of each scheduling method for solving practical problems.

Evaluating indicator	Manual scheduling	NSGA-II	Our method
f_1/min	72	42	39
Number of noninferior solutions/piece	N/A	9	14
Dispatching time/S	540	16	24
Dependence on people	Large	Small	Small

applicability of the algorithm, the method is suitable to be used in related domains.

6. Conclusion and Future Strategy

In this paper, the population initialization, cross-variation method and elite retention strategy of NSGA-II were improved. The method introduced intends to effectively ensure the population diversity and improve the global and local search capability of the algorithm. The hybrid multiobjective genetic algorithm of the method utilizes NSGA-II as the main and acoustic search as the supplement algorithm. The advantages of both the algorithms are fully combined in one to improve the solution quality. The feasibility and effectiveness features of the algorithm were assessed for solving MO-FJSP. Experimentations were conducted with the standard algorithms: Kacem test set, BRdata data set, and actual production cases. Outcomes of the assessments reveal that the method proposed has better practical significance.

In future, it is planned to augment the method so that the algorithm should dynamically study its own characteristics in depth. This will enable the algorithm to explore the improvement strategies under different target requirements. By that way, the hybrid multiobjective genetic algorithm will continuously improve, the solution quality will be enhanced and efficiency of the algorithm will be increased desirably.

Data Availability

The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The author declares no financial and personal relationships with other people or organizations that can inappropriately influence this work.

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