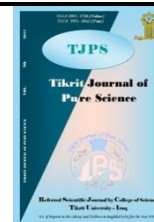




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job shop scheduling problem: literature review

Marrwa Abd-AlKareem Alabajee , Anfal A. Fadhil , Rasha Gh. Alsarraj

Software Department, College of Computer Science & Mathematics, University of Mosul, Mosul , Iraq

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Corresponding Author:

Name: Marrwa Abd-AlKareem

E-mail:

marrwa.zedan@uomosul.edu.iq

Tel:

ABSTRACT

As an extension of the Job Shop Scheduling (JSP), Flexible job-shop Scheduling Problem (FJSP), can be defined as one of the most significant problems in up-to-date manufacturing systems, recently a lot of studies have been conducted to address FJSP. Initially, the problem can be defined, after that, literature can be categorized based on different methods that have used from the year 2010 for the resolution of this problem. Lastly, certain conclusions have been provided based on the results of the conducted survey.

1. Introduction

The business corporations working to streamline their production procedures, meet the requirements of customers as well as, accommodating their various demands. Thus, there has been a massive requirement for job shop for accommodating such requirements [1].

The computational grids were developed as a novel method for solving large-scale problems in science engineering, as well as businesses. The systems of grid computing involved a set of resources and programs that have subjected to distribution among the grid machines. the main aim has managing systems in a way that set related to jobs that have achieved in the shortest possible time [2].

Scheduling, as well as process planning in the shop, have been specified as the main problem that should be tackled in the manufacturing systems[3].

for fetching maximum utilization of the CPU and gained loudly throughput There is a need to schedule the system and user processes by the operating system [4].

Also, this have very important since such systems should be systematically dealing with the production items as well as assigning resources about such items. Furthermore, resources to complete operations for the job have specified typically throughout the process planning [3].

The process of scheduling involves resource allocation over time for performing the collection of the tasks[5].

Job scheduling can be considered as a solution that increases effectiveness and reducing makespan (maximal completion time) that is related to all the jobs. The main goal of job scheduling has to determine that job that must be achieved at which time and in which machine. Concerning grid environments, job scheduling, as well as, effective resource management, have of high importance. Job scheduling which is adequately-done might be helping applications and users for being supplied with the services in an optimum way, also all grid resources might be maximally and optimally used [2]. FJSP can be considered as generalization related to classical job shop problems. Each one of the operations has processed on a certain machine it has selected from the finite subset that related to candidate machines.

The major goal is finding allocation concerning each one of the operations and defining sequences related to the operations on each one of the machines for minimizing makespan due to its NP-hard nature [6].

FJSP will be providing approximations related to real-world scheduling situations, yet combination regarding routing as well as sequencing problems presenting more complexity in comparison to classical JSP that was verified for being NP-hard. It

has an extra complex NP-hard problem, also can be solved with extra complexity [7].

This study will be presenting a novel review concerning FJSP. In which a lot of works will be reviewed as well as suggesting a classification system based on the type related to algorithms utilized for solving FJSP, this study has categorized in the following way. Problem definition provided in section 2. Section 3 providing the FJSP based on optimization Algorithms. While rounding the paper up and conclusions are provided in section 4.

2. Definition of fjsp

With regard to processing jobs (n) on machines (m), the problems have finding optimum solutions that achieve maximum or minimum values with regard to objective functions [8].

With regard to FJSP, each one of the operations might be allocated to a single machine from set regarding provided one and after that sequenced withing precedence constraints. There are three sets related to the n jobs $J = \{J_1, J_2, J_3, \dots, J_K, \dots, J_n\}$ which will be processed on regarding m machines,

$M = \{M_1, M_2, M_3, \dots, M_K, \dots, M_m\}$. Each one of the jobs consisting of n_i operations,

$O_i = \{O_{i1}, O_{i2}, \dots, O_{ij}, \dots, O_{ini}\}$, in which O_{ij} as well as n_i denoting j th operation related to the job i as well as the number of operations related to the job i . Machine processing the operation O_{ij} has been indicated as M_K from certain provided machines referred to as M_{ij} , in which M_{ij} denoting set related to available machines with regard to the operation O_{ij} as well as $(M_{ij} \subset M)$. The total flexibility, as well as the partial flexibility, have been 2 types related to FJSP. The latter indicates provided machines M_{ij} processing on operation O_{ij} have been sub-set related to M , while the former indicates that the provided machines M_{ij} processing on operations O_{ij} including all the machines of M [9].

Assumptions related to FJSP have in the following way [10]:

- (1) Each one of the machines could be utilized at time zero.
- (2) Each one of the jobs could have processed at time zero.
- (3) Each one of the machines could just process a single operation at a time.
- (4) A soon as starting operation on a machine, it won't be interrupted anymore.
- (5) Sequences related to operations about all jobs have pre-specified.
- (6) Neither release times nor the due dates have defined.
- (7) Transportation time among the machines has not specified.

(8) All the machines were not identical all the time.

The task has been determining assignments as well as a sequence of the operations for minimizing a lot of scheduling criteria, there have been many aims related to the scheduling criteria which applied in the literature review [9][11]:

1. C_M : Makespan or maximal completion time related to the machines

$$C_M = \max_{1 \leq k \leq m} \{C_k\}$$

2. W_T : Machines' total workload, that has been machines' total working time.

$$W_T = \sum_{i=1}^n \sum_{j=1}^{n_i} \sum_{k=1}^m p_{ijk} x_{ijk}$$

3. W_M : Maximal workload or Critical machine workload, which has been the biggest workload in machines.

$$W_M = \max_{1 \leq k \leq m} \sum_{i=1}^n \sum_{j=1}^{n_i} p_{ijk} x_{ijk}$$

In which p_{ijk} denoting executing time that is related to the operation O_{ij} on machine M_K and M_{ijk} is:

$$x_{ijk} = \begin{cases} 1 & \text{if machine } k \text{ is selected for the operation } O_{ij} \\ 0 & \text{otherwise} \end{cases}$$

4- Flow Time (FT) has been sum related to job completion times.

$$FT = \sum_{i=1}^n C_i$$

Based on flexibility, FJSSP has been categorized into these two sub-problems[12].

1- (DRs), as well as mathematical programming (MP) methods, also there have been a Total FJSSP: each one of the operations could be processed on any of (m) machines in the shop.

2- Partial FJSSP: in which certain operations have been possible on part related to available (m) machines in the shop.

3. The Fjsp Based on Optimization Algorithms

A lot of approaches have utilized for solving the FJSP since initially provided in the year 1990. Such approaches have based on artificial intelligence (AI), dispatching rules a few types of research indicating that hybrid over one approach. Some approaches have provided in the following way [8].

Mixed-integer (two step)

In the year 2010, a study conducted by Cemal et al. suggesting a model dealing with 2 NP-hard optimization problems: FJSPs which involve routing as well as sequencing sub-problems, also FJSP with the process plan flexibility (FJSP-PPFs) which further involve process plan selection sub-problem. Their work has been conducted in two steps. With regard to the first step, a mixed-integer linear programming model (MILP-1) has been created with regard to FJSP as well as put to comparison to alternative models in the literature (Model F) with respect to the computational efficiency. While in the other step,

another MILP, modification related to the MILP-1, Makespan has been used as single performance measure with regard to MILP-1, since that it has been single measure utilized in MILP-1. Makespan is depend on as the one performance metric in MILP-1 because the fact that it is the one metric used in the model that MILP-1 is apply in this work, namely Model F. and Because it is an extension of MILP-1, they selected retain the makespan as the one metric in MILP-2, However, it must be noted that additional metrics such as total delay The number of tardy jobs and the scale of carrying machines can easily be combined into MILP-2[13].

GA and chaotic local

In the year 2010, a study conducted by Libo and Xuejun, suggested a model which developed a method hybridizing GA as well as a chaotic local search for the purpose of exploiting GA's "global search ability" as well as "the local search ability" on the basis of chaotic sequence to solve FJSP with the makespan criterion, a little percentage of the elite Individuals are input into the first population of the ligation GA proximity speed, Effective mutations and crossover operators are certified to avoid useless solutions and accelerate optimal solution emergencies. During the local search, they depend on the Logistic chaotic series to search the neighborhood solutions about the better individual of the current generation. A large-scale computational study shows that proposed algorithm have high performance compare another genetic algorithm and a genetic algorithm of culture for the same issue. The experiments prove that the suggested algorithm It can be used to solve FJSP actively and stable [7].

Hybrid Pareto-based Artificial Bee Colony (HABC)

In the year 2011, a study conducted by Jun-qing et al suggested a hybrid Pareto-based artificial bee colony (HABC) to solve multi-objective FJSP. With regard to the hybrid algorithm, each one of the food sources specified through two vectors, for instance, operation scheduling vector as well as the machine assignment vector. Also, ABC has been divided into three groups (scout bees, onlookers, as well as employed bees). Also, an external Pareto archive set has been provided for recording non-dominated solutions which have been indicated so far. For the purpose of balancing explorations as well as exploitation ability related to an algorithm, scout bees in the hybrid algorithm have been divided into two parts. In one part, scour bees randomly performing search in pre-defined region, whereas each one of the scout bees in other parts selecting a randomly single non-dominated solution from the Pareto archive set. Furthermore, test samples are coming from the Kacem instances set, Extensive experiments depend on benchmark examples are performed at different metrics, and comparisons with other modern algorithms show the Suggested algorithm is more efficacy [14].

Hybrid Algorithm: Chaos PSO and GA

In the year 2011, a study conducted by Jianchao et al based on FJSP's characteristics, the authors suggested a hybrid algorithm that combines chaos PSO as well as GA for solving FJSP. Also, with induction related to enhanced Kacem assignments system, the initialization method has been provided. Also, coverage related to state space has been enhanced on the basis of logistic maps. The experimental results related to different benchmark instances verifying this algorithm's efficiency, also showing that such approach is outperforming a few of current approaches, new initialization approach has been suggested on the basis of enhanced Kacem assignments method. Based on characteristics related to FJSP to beat GA and PSO's weakness, The chaotic optimization model is applied, which is a new methodical random search with ergodicity, and a self-adaptive the parameters has integrated to enhance solution efficiency and keep high quality [15].

Gravitational Search Algorithm GSA

In the year 2012, a study conducted by Behnam et al. suggested a novel algorithm were with regard to flexible jobs hop scheduling problem systems FJSSP-GSPN which is on the basis of algorithm GSA. FJSP has been modeled through the color Petri net in addition to the CPN tool, after that the scheduled job has been programmed through GSA. Furthermore, experimental results are showing that the suggested approach has adequate performance when compared to the other algorithms, the aim of scheduling is minimizing maximum completion time related to all operations, that has been referred to as Makespan[16].

Improved genetic-simulated annealing algorithm

In the year 2013, a study conducted by Min et al. suggested a mathematical model that is related to the FFS problem, which has been on the basis of energy-efficient mechanisms, also specified for solving multi-objective optimization. Due to the fact that FFS has been referred to as NP-hard problem, which is enhanced, as well as genetic-simulated annealing algorithm has been used for making trade-offs between makespan as well as overall total energy consumption for implementing feasible scheduling. Gravity search algorithms give very good results to many problems, so they are considered one of the best effective algorithms to find solutions with adequate and high quality [17].

Constructive Procedure

In the year 2014, a study conducted by Mohsen provided simply model extendable heuristic on the basis of constructive procedures. Such algorithm applies flexible, comprehensive, as well as accurate criterion related to the scheduling job operations, also construct high-quality, feasible solutions. A lot of factors impacting the solution's quality utilized and each of those factors has two weights (involving variable weight and constant weight) that have been specified. Through setting various values to variable

weights, there will be various solutions that are created and assessed via makespan. The algorithm was tested on reference examples from the literature in order to compute its performance. From the results show the suggested heuristic can obtain Excellent solutions in a very short time and It can be compared even with metaheuristic algorithms [18].

Firefly Algorithm and local search

In the year 2015, a study conducted by Karthikeyan et al. suggested a discrete firefly algorithm (DFA) which has been combined with the local search (LS) approach for enhancing the accuracy of searching as well as sharing of information between fireflies. Also, certain experimental results on recognized benchmark instances as well as comparing with the other recent algorithms showing that the suggested algorithm has been efficient and feasible with regard to multi-objective FJSP [19].

Hybrid Algorithm: GA and Tabu Search

In the year 2015, a study conducted by Juan Jose Palacios et. al suggested heuristic approach for generating initial solutions advantage from flexible nature that is related to the problem as well as generating diverse and high-quality initial solutions that are providing starting points related to GA, improving the exploitation ability. Also, the developed TS algorithm has been utilized for each one of the newly created chromosomes in GA. Major points related to TS has bene neighborhood structure. Also, the main aim is minimizing the total time required for completing all the jobs, referred to as makespan. The study suggested two novel structures. With regard to the first structure, they indicated that it is verifying connectivity and feasibility, the former ensures asymptotic convergence in the probability to globally optimal solutions. The other neighborhood has been acquired through involving filtering approach which trims first structure through discarding the non-enhancing neighbors; such neighborhood keeping feasibility feature as well as reducing the size related to first one at the costs of losing the connectivity. Lastly, an approach on the basis of constraint propagation was provided for allowing speeding up the evaluations related to novel chromosomes. they have put to test the subsequent algorithm, HGTS, on wide set with (205) instances, specifying deterministic as well as fuzzy instances related to FJSP from literature for enhancing the importance of the work. Also, widespread experimental results showing that not just does hybrid algorithm benefiting from the synergy among the components, enhancing them in the case when separately run for the same time, yet it has been considered competitive with other modern approaches in solving fuzzy and crisp instances, offering novel solutions for some test instances [20].

Hybrid Algorithm: Taguchi method and GA

In the year 2015, a study conducted by HAO-CHIN CHANG et. al specified FJSP as well as a developed new approach which encodes possible solutions in

genes related to initial chromosomes with regard to GA, also embed Taguchi approach in evolution phase for the purpose of facilitating acquiring offspring of high-quality as well as efficiently increasing convergence speed that is related to GA; thus, the suggested algorithm has been possible for identifying fairly optimum solutions and avoiding local optimal solutions. The major aim is minimizing the total order completion time (makespan) with the use of the Hybrid Taguchi-Genetic Algorithm (HTGA) for the purpose of solving FJSP. There are two numerical experiments have been carried out to evaluate the suggested algorithm's performance in relation to that related to Brandimarte MK1–MK10 benchmarks. Furthermore, the first experiment involves comparing the suggested algorithm and the conventional GA. While the other experiment involves comparing the suggested algorithm with the other approaches. The results are demonstrating that the suggested algorithm outperforming the other approaches comparing with them and efficiently overcoming the encoding problem which happen in the case when GA has been utilized for solving FJSP [21].

Hybrid Algorithm: shifting bottleneck heuristic (SBH) with the proposed local search approach and a variable neighborhood search (VNS)

In the year 2016, a study conducted by Oleh Sobeyko, Lars Mönch specified scheduling problems with regard to the flexible job shops which consist of un-related and identical parallel machines. Also, performance measures have been total weighted tardiness (TWT). Furthermore, the major contribution has been an effective iterative local search method with regard to the flexible job shops as well as TWT measures with the use of disjunctive graph representations. Escape from the local optima has been guaranteed with the use of simulated annealing acceptance criteria. Moves' evaluation has been based on dynamic topological ordering that is related to the disjunctive graph. The study hybridized shifting bottleneck heuristic (SBH) with suggested local search methods as well as a variable neighborhood search (VNS). Furthermore, the list scheduling approaches with regard to various due date-oriented dispatching rules have been put to discussion. Also, the suggested heuristics have been put to comparison through computational experiments that are related to the problem instances provided in literature as well as set related to novel large-size problem instances. Furthermore, the local search approach can determine solutions for high-quality in short computing time. In the case of increasing processing flexibility, for instance, the number of parallel machines, enhancements related to advanced approaches put to comparison with the list scheduling approaches will be decreased. With regard to the identical parallel machines, algorithms of SBH-type outperforming local search schemes in terms of TWT. Yet, SBH requiring increased computing time [22].

Artificial Bee Colony (ABC)

In the year 2016, a study conducted by Kai Zhou Gao et. al provided two novel approaches. The first one specifying that the new job insertion, as well as the fuzzy processing time, have been modeled from the re-manufacturing industries as well as two constraints have been specified with regard to FJSP. Also, the fuzzy processing time has been utilized for describing processing time's uncertainty. Furthermore, re-scheduling has been achieved in the case when jobs have been inserted into the current scheduling solution. While the second one specifying that the two-stage (TABC) has been suggested for solving FJSP that has two constraints. A lot of new solutions generate and improve strategies that have been suggested for improving the TABC's performance. The main aim is minimizing maximum fuzzy completion time. Furthermore, the suggested TABC in addition to its variants has been solving eight instances from the re-manufacturing engineering in an effective way. There have two optimum variants related to TABC that have been put to comparison with seven current algorithms over five benchmark conditions with the fuzzy processing time. Also, the comparisons and results showing the effectiveness of TABC to solve FJSP with the re-manufacturing constraints [23].

Hybrid Algorithm: ABC and PSO

In 2016, a study conducted by Muthiah et al. suggested methodology hybridization that is related to ABC and PSO optimization approaches for minimizing makespan time that is related to shops. There are twenty types regarding the benchmark problems that have been specified with regard to the process of JSSP. In the approach of ABC, scout bee operations according to the PSO approach updating particles' position and the process velocity. Optimum solutions are acquired in HPA in comparison to PSO and ABC. The results indicating that optimal makespan time fitness function accuracy that is related to the suggested approach has been 94.23% in comparison to the other processes of optimization [24].

Hybrid Algorithm: Tabu Search (TS) and Genetic Algorithm (GA)

In the year 2016, a study conducted by Xinyu Li and Liang Gao suggested an effective hybrid algorithm (HA) that is hybridizing (GA) as well as tabu search (TS) with regard to FJSP and the aim of minimizing makespan. Also, GA that has effective global searching capability has been applied for performing explorations, also TS that as excellent local searching capability has been utilized for performing exploitations. Thus, the suggested HA has an excellent searching capability and might be balancing intensifications as well as diversifications effectively. For the purpose of solving FJSP efficiently, the effective encoding approach, neighborhood structure as well as genetic operators have been using such an approach. There are six well-known benchmark

instances (involving 201 open problems) related to FJSP that were utilized for evaluating the suggested HA's performance. Furthermore, comparisons in suggested HA and modern algorithms have been offered for showing the efficiency related to the suggested approach. Computational time related to the suggested HA was put to comparison with the other algorithms. Also, experimental results are showing that the suggested HA accomplished considerable enhancement to solve FJSP in spite of computational time as well as the solution accuracy. Also, the suggested approach obtain novel best solutions with regard to many benchmark problems[25].

Multi-Objective PSO

In the year 2016, a study conducted by Song Huang et. al presented multi-objective particle swarm optimization (MOPSO) which will integrate with variable neighborhood search for efficiently addressing FJSP. Initially, dispatching rules (DR), as well as assignment rules (AL), have been offered for initializing the population. After that, special discrete operators have been developed for providing novel as well as the earliest completion machine (ECM) has been used in disturbance operator for escaping optima. Secondly, the global-best archive (social memory) as well as the personal-best archive (cognitive memory), that has updated through pre-defined non-dominated archive update strategies, have been simultaneously developed for preserving non-dominated individuals as well as selecting the personal-best positions in addition to global-best position. Lastly, there are three neighborhoods have been supplied for searching neighborhoods related to the global-best archive with regard to improving local searchability. Also, there are three objectives related to the FJSP scheduling has been optimizing (makespan, critical machine workload as well as the total workload). The suggested algorithm has been estimated with the use of Brdata instances as well as the Kacem instances, also comparisons with certain other methods showing the efficiency related to the suggested algorithm with regard to FJSP [9].

Dispatching Algorithm

In the year 2016, a study conducted by Miguel Ortiz et. al, suggested a dispatching algorithm with inclusions related to the throughput as the second rule that is related to the operation selection was suggested for solving FJSP in the apparel industries. Throughput, days of delay, earlier date as well as monthly demands have utilized as rules related to the operation selection. The main aim of this work has been minimizing average tardiness related to the orders as well as getting low tardiness scores in those with elevated throughput. Furthermore, a case study in the apparel industries has indicated for proving the validity related to the suggested approach. The results indicating that this approach outperforming company solutions as well as other algorithms (Pareto-based grouping discrete harmony search algorithm

(PGDHS) in addition to HHS/LNS (ref.21)) upon decreasing the average tardiness by 61.1%, 2.63% as well as 1.77%. Also, throughput's inclusion in the model caused low tardiness for orders with increased speed for making money[26].

Hybrid algorithm: PSO and Tabu search

In the year 2016, a study conducted by Asen and Vassil suggested the algorithm which combines Tabu search method and PSO, utilizing neighborhoods with single operation movement, in addition to final local search with the use of neighborhoods with one or two operations movement, as can be seen in the illustrative example. The new algorithm has referred to as "PSO&TS", also it can be utilized for large size FJSP, From the results, it was found that the proposed algorithm is good and can be applied to large-size issues because it has proven very effective [27].

Particle Swarm Optimization (PSO)

In the year 2016, a study conducted by Mehdi et al. suggested a novel heuristic technique on the basis of PSO for the purpose of scheduling jobs in the grid environments. The suggested algorithm might be creating optimal scheduler for completing jobs in the lowest makespan and flowtime (objectives related to the resource allocation has been minimizing flowtime and makespan by means of PSO.) Each one of the particles specified to be a likely solution to resource allocation. It is indicating that each one of the particle vectors might be as long as N that specifies the overall number related to the input jobs. Each one of the elements in the vector has been random integer in the range (1-M) (where M specified as the number of the resources). The suggested algorithm has created an ideal scheduler to complete tasks in minimum flow time and makespan [2].

Hybrid ACO algorithm

In the year 2017, a study conducted by Jianshe Wu et al. suggested hybrid ACO on the basis of 3-D disjunctive graph models through combining elitist ant systems, max-min ant systems as well as staged parameter control mechanisms, optimizing FJSP for minimizing long completion time, early/delay penalty costs, average idle time that is related to machine, in addition to production costs. They verified that the efficiency related to algorithm and model through example (received, processed, accepted through Chinese representation office) [28].

Ant colony optimization (ACO)

This algorithm was effective in dealing with FJSP. Yet, there are two major drawbacks related to basic ACO which are the low computational efficiency as well as the local optimum. For the purpose of overcoming such two drawbacks, improved ACO has suggested in the year 2017 via Lei Wang et al., for the purpose of optimizing (minimizing) FJSP makespan. The next aspects have achieved in an improved ant colony optimization (IACO): selecting machine rule problems, initializing the uniform distributed mechanisms related to ants, changing the guiding mechanism of pheromone, selecting the node

approach, as well as updating the mechanism of pheromone. Actual production instances, as well as two sets regarding defined benchmark instances, have been put to test, also certain comparisons with a few of the other methods verifying the efficiency of the suggested improved ACO. The results indicating the suggested IACO might be providing better solutions for inadequate computational time[10].

Bat algorithm

In the year 2017, a study conducted by Hua Xu et. al utilized the enhanced GA, DPSO, as well as BAT algorithm for solving dual-DFJSP. About FJSP with the machine selection flexibility as well as process sequence flexibility in the process design, characteristics, as well as types related to the machine selection as well as the process sequence flexibility have evaluated. Also, the mathematical model related to dual-FJSP has created, and an enhanced bat algorithm has suggested. The main aim of dual-FJSP has sought an adequate schedule that takes little time for completing all the operations. Certain experiments have conducted on the actual examples, it might be indicated from experimental results that optimization ability, as well as robustness related to the suggested algorithm, have better in comparison to DPSO and GA. This has showing that the suggested algorithm has very important to solve FJSP, also it has been one of the effective scheduling algorithms [29].

Hybrid Metaheuristics-based Multiagent Model

In the year 2018, a study conducted by Housseem Eddine Nouri et al. showed hybridization related to two metaheuristics in the holonic multiagent model for the purpose of solving FJSP. Such a novel method is following 2 principal stages. With regard to the first stage, GA has been utilized through the scheduler agent with regard to global explorations related to search space, while in the second stage, local search method presented through set regarding cluster agents for improving the final population's quality. The numerical tests have been achieved for evaluating the performance related to such a method on the basis of 4 datasets regarding defined benchmark instances in FJSP literature, in which experimental results showing its effectiveness when compared to the other methods. The main aim of such a problem has been finding a schedule reducing end date related to the last operation of the jobs set that has been makespan [30].

Operations Permutation-based Discrete Harmony Search (EOP-DHS)

In the year 2018, a study conducted by Mehdi et al. suggested an Effective Operations Permutation-based Discrete Harmony Search EOP-DHS method related to FJSSP with the Makespan criterion. Also, such a method adopting integrated two-part "affectation-sequencing" representations related to solution harmony as well as suggested improvisation operators especially used to integer-valued as well as operations permutation-based utilized coding approach. Furthermore, Modified Intelligent

Mutations (MIMs) operator has been used to the system for the purpose of enhancing the total searchability. Furthermore, the implemented numerical experimentations on the 188 benchmarking instances validating suggestions fairly to representative set regarding formerly used metaheuristic methods to the FJSSP with Makespan criteria. Also, the major contributions related to the study have been extended with experimental procedures verifying the efficiency related to the used permutation-based HS approach for the resolution that is related to the combinatorial optimization problems [31].

Genetic Algorithm (GA)

In the year 2016, a study conducted by Ming et al. suggested enhanced GA with the use of opposition-based learning, also the mathematical model has been created to minimize makespan. About the properties related to FJSP, the have dual chain structure coding approach has been utilized for encoding chromosomes. Also, the population has initialized with the hybrid technique. Furthermore, genetic operations have carried out in population among two efficient crossover approaches and two mutation approaches, that have suggested based on the context coding approach. Finally, case-studies based on certain typical benchmark examples have implemented for evaluating the suggested algorithm. Also, the experimental results are showing that such enhancements allowing GA for reaching solutions of high quality in a short time[32].

In the year 2017, a study conducted by Abd Elrahman et al. showed enhanced GA to optimize resource utilization regarding FJSP in dynamic environments. Also, the experimental results indicating the capability of enhanced GA to effectively scheduling the static job shop, FJSP. Also, the possibility of accommodating novel events that are disturbing the system efficiently. Algorithms have utilized to set related to static benchmark problems which are having machines between (4-10) to indicate the major adequate parameters related to GA. The machine utilization specified in the makespan has selected for measuring the performance related to the suggested algorithm[1].

In the year 2019, a study conducted by Piotr et al. Developed a novel variant has related to multi-objective FJSPs where some commodities could be created with a set of recipes. Furthermore, a single commodity might have created with some distinctive recipes executions producing various amounts of commodities and that have various resource compatibility as well as manufacturing time. The aim

has minimized makespan as well as producing commodities in amounts extremely close to ordered ones, for instance, minimizing discrepancies between ordered quantities as well as manufactured ones for all resources. Chromosome encoding about the have specified problem, was suggested and classic MOEA/D multi-objective GA has tuned with customized problem-specific genetic operators: elitism as well as mutation. Also, the applicability has related to the suggested method has been estimated experimentally, also it is outperforming classic multi-objective GAs [33].

Modified Iterated Greedy (IG) algorithm

In the year 2019, a study conducted by Ghiath et al. presented a modified (IG) algorithm, easier metaheuristic which can be coded and reproduced easily. Also, classical IG has been separated into two phases for handling two sub-problems related to the FJSP, also it has been combined with the setting related to dispatching rule (DR) for solving FJSP. There are three experiments regarding overall thirty-five benchmark problems that have been utilized for testing the performance regarding the suggested algorithm. The aim specified in this work has been minimizing the makespan. Furthermore, the effectiveness and simplicity related to DR and IG might cause an efficient approach which takes less computation time, also it might be implemented easily. empirical results show that the algorithm can discovery the universal optimum solution for few and intermediate scale instances. For big scale instances, the modified (IG) algorithm has gained optimum solutions for a few instances and high optimum solutions for a few other instances [8].

Discrete Particle Swarm Optimization Algorithm

In the year 2020, a study conducted by Xiao-Lin et al. proposed A discrete particle swarm optimization algorithm with adaptive inertia weight (DPSO-AIW) is suggested to find solution of the multiobjective Flexible Job-shop Scheduling issue. The algorithm depend on a two-layer coding structure to represent the chromosomes, called operation sequence (OS) and machine assignment(MA). numerical simulations were apply using two sets of studies, These include five instances of Kacem and three instances of BRdata. The simulation results of the proposed algorithm were compared with the results of other algorithms show the suggest algorithm have Efficacy and ability for solving multiobjective FJSP .After doing several experiments, they discovered that the DPSO-AIW algorithm works quickly to find best solutions to cases with more flexibility[34].

Table1: shows a summary of all previous work mentioned in this review.

No.	Article	application	Algorithm and shop details	Objective function
1.	Cemal et al. (2010)	Research	mixed-integer	Makespan
2.	Libo and Xuejun (2010)	Research	genetic algorithm with chaotic local search	Makespan
3.	Jianchao et al. (2011)	Research	chaos particle swarm optimization and genetic algorithm	Makespan
4.	Jun-qing et al. (2011)	Research	hybrid Pareto-based artificial bee colony (HABC)	Makespan, Maximal workload, Total workload
5.	Behnam et al. (2012)	Research	gravitational search algorithm	Makespan
6.	Min et al. (2013)	Industry	improved genetic-simulated annealing algorithm	Makespan Total Energy
7.	Mohsen (2014)	Research	constructive procedure	Makespan
8.	Karthikeyan et al. (2015)	Research	firefly and local search	Makespan, Maximal workload, Total workload
9.	HAO-CHIN et al. (2015)	research	Hybrid Taguchi-Genetic Algorithm	Makespan
10.	Juan et al.(2015)	research	genetic algorithm hybridized with tabu search	Makespan
11.	Kai et al.(2016)	research	Artificial bee colony algorithm	minimize the maximum fuzzy completion time
12.	Oleh and Lars (2016)	research	hybridize the shifting bottleneck heuristic (SBH) with the proposed local search approach and a variable neighborhood search (VNS) approach	the total weighted tardiness (TWT)
13.	A Muthiah et al.(2016)	research	hybridization of the Artificial Bee Colony (ABC) and Particle Swarm Optimization (PSO) optimization techniques	Makespan
14.	Ming et al. (2016)	research	improved genetic algorithm using opposition-based learning	Makespan
15.	Mehdi et al. (2016)	Research	particle swarm optimization	Makespan, Flow time
16.	Asen and Vassil (2016)	Research	Particle Swarm Optimization procedure with Tabu search	Makespan
17.	Song et al. (2016)	research	multi-objective particle swarm optimization	Makespan, total workload as well as critical machine workload.
18.	Xinyu and Liang (2016)	research	hybrid algorithm (HA) which hybridizes the genetic algorithm (GA) and tabu search (TS)	minimize the Makespan
19.	Miguel et al. (2016)	Industry	dispatching algorithm	Minimizing average tardiness related to orders and getting low lower tardiness scores in those with the higher throughputs
20.	Lei et al. (2017)	research	improved ant colony optimization (IACO)	Makespan
21.	Jianshe et al. (2017)	research	hybrid ACO algorithm	Minimizing longest completion time, early/delay penalty costs, average idle time related to machine, as well as production costs
22.	Abd Elrahman et al. (2017)	research	improved genetic algorithm (IGA)	Makespan
23.	Hua et al. (2017)	research	improved bat algorithm, discrete particle swarm optimization (DPSO) and genetic algorithm	minimum time to complete all operations
24.	Houssem et al.(2018)	research	hybridization of two metaheuristics within a holonic multi agent model	Makespan
25.	Mehdi et al. (2018)	research	Operations Permutation-based Discrete Harmony Search (EOP-DHS) approach	Makespan
26.	Ghiath et al. (2019)	research	modified iterated greedy (IG) algorithm	Makespan.
27.	Piotr et al.(2019)	Industry	multi-objective genetic algorithm with specific genetic operators	Makespan, minimize discrepancies between ordered quantities as well as manufactured ones with regard to each one of the resources.
28.	Xiao-Lin et al. (2020)	research	A discrete particle swarm optimization algorithm with adaptive inertia weight	The maximal completion time of machines, the bottleneck machine workload, the total workload of machines.

4. Conclusion

The flexible job shop scheduling problems FJSSPs are one of the most concerned problems currently in manufacturing, it is an extension of typical JSS problems and is considered difficult to solve due to their NP-hard nature. Researchers and practitioners have tried to develop efficient solution techniques/methods during the last ten years. This paper investigates FJSSPs and reviews all the solution techniques/methods published in the literature to solve FJSSPs.

Metaheuristics have been used more widely as compared to other methods. The most popular

References

- [1] Elgendy, A. E., Hussein, M. and Elhakeem, A. (2017). Optimizing Dynamic Flexible Job Shop Scheduling Problem Based on Genetic Algorithm. *International Journal of Current Engineering and Technology*, **7(2)**:368-373.
- [2] Effatparvar, M., et al. (2016). Swarm Intelligence Algorithm for Job Scheduling in Computational Grid. 7th International Conference on Intelligent Systems, Modelling and Simulation(ISMS). Bangkok: p. 315-317.
- [3] Lee, S., et al. (2012). Flexible job-shop scheduling problems with 'AND'/'OR' precedence constraints. *International Journal of Production Research*, **50(7)**:1-23.
- [4] Hussein, Q. M. and Hasoon, A. N.(2017). Dynamic Process Scheduling Using Genetic Algorithm. Annual Conference on New Trends in Information & Communications Technology Applications-(NTICT'2017) 7 - 9 March 2017: p. 111-115.
- [5] Chaudhry, A. I. (2012). Job shop scheduling problem with alternative machines using genetic algorithms. *Journal of Central South University of Technology*, **19(5)**:1322-1333.
- [6] Tanga, J., et al. (2011). A Hybrid Algorithm for Flexible Job-shop Scheduling Problem. *Procedia Engineering*, **15(2011)**:3678-3683.
- [7] Song, L. and Xu, X. (2010). Flexible Job Shop Scheduling Problem Solving Based on Genetic Algorithm with Chaotic Local Search. Sixth International Conference on Natural Computation, ICNC 2010, Yantai, Shandong, China, 10-12 August 2010.
- [8] Al Aqel, G., Li, X. and Gao, L. (2019). A Modified Iterated Greedy Algorithm for Flexible Job Shop Scheduling Problem. *Chinese Journal of Mechanical Engineering*, **32(21)**:1-11.
- [9] Huang, S. et al. (2016). Multi-objective flexible job-shop scheduling problem using modified discrete particle swarm optimization. *SpringerPlus*, **5(1432)**:1-22.
- [10] Wang, L. et al. (2017). Flexible Job Shop Scheduling Problem Using an Improved Ant Colony Optimization. *Hindawi Scientific Programming*, **2017(3)**:1-11.
- [11] Weber, R. (1982). Scheduling Jobs with Stochastic Processing Requirements on Parallel Machines to Minimize Makespan or Flowtime. *Journal of Applied Probability*, **19(1)**:167-182.
- [12] Kacem, I., Hammadi, S. and Borne, P. (2002). Pareto-optimality approach for flexible job-shop scheduling problems: hybridization of evolutionary algorithms and fuzzy logic. *Mathematics and Computers in Simulation*, **60(3-5)**:245-276.
- [13] Özgüven, C., et al. (2010). Mathematical models for job-shop scheduling problems with routing and process plan flexibility. *Applied Mathematical Modelling*, **34(6)**:1539-1548.
- [14] Li, J, et al. (2011). A Hybrid Artificial Bee Colony Algorithm for Flexible Job Shop Scheduling Problems. *Int. J. of Computers, ommunications & Control*, **6(2)**:286-296.
- [15] Tanga, J., et al. (2011). A Hybrid Algorithm for Flexible Job-shop Scheduling Problem. *advance in control engineering and information science*, **15(2011)**:3678-3683.
- [16] Barzegar, B., et al. (2012). Solving Flexible Job-Shop Scheduling Problem Using Gravitational Search Algorithm and Colored Petri Net. *Journal of Applied Mathematics*, **2012**:1-20.
- [17] Dai, M., et al. (2013). Energy-efficient scheduling for a flexible flow shop using an improved genetic-simulated annealing algorithm. *Robotics and Computer-Integrated Manufacturing*, **29(5)**:418-429.
- [18] Ziaee, M. (2014). A heuristic algorithm for solving flexible job shop scheduling problem. *The International Journal of Advanced Manufacturing Technology*, **71**:519-528.
- [19] Karthikeyan, S., et al. (2015). A hybrid discrete firefly algo-rithm for solving multi-objective flexible job shop scheduling problems. *International Journal of BioInspired Computation*, **7(6)**:386-407.
- [20] Palacios, J. J. et al. (2015). Genetic tabu search for the fuzzy flexible job shop problem. *Computers & Operations Research*, **54**:74-89.
- [21] Chang, H.-C. et al. (2015). Solving the Flexible Job Shop Scheduling Problem With Makespan Optimization by Using a Hybrid Taguchi-Genetic Algorithm. *IEEE ACCESS*, **3**:1740-1754.
- [22] Sobeyko, O., Mönch, L. (2016). Heuristic approaches for scheduling jobs in large-scale flexible

job shops. *Computers & Operations Research*, **68**:97-109.

[23] Gao, K. Z. et al. (2016). Artificial bee colony algorithm for scheduling and rescheduling fuzzy flexible job shop problem with new job insertion. *Knowledge-Based Systems*, **109**:1-16.

[24] Muthiah, A., Rajkumar, A. and Rajkumar, R. (2016). Hybridization of artificial bee colony algorithm with particle swarm optimization algorithm for flexible job shop scheduling. *Energy Efficient Technologies for Sustainability (ICEETS)*, 2016 International Conference on: p. 896-903.

[25] Li, X. and Gao, L. (2016). An effective hybrid genetic algorithm and tabu search for flexible job shop scheduling problem. *International Journal of Production Economics*, **174**:93-110.

[26] Ortiz, M. et al. (2016). Solving Flexible Job-Shop Scheduling Problem with Transfer Batches, Setup Times and Multiple Resources in Apparel Industry. 7th International Conference, ICSI 2016, Bali, Indonesia, June 25-30, 2016, Proceedings, Part II: P. 47-58.

[27] Tochev, A. and Guliashki, V. (2016). A Hybrid Metaheuristic Algorithm for Flexible Job Shop Scheduling "PSO&TS". *International Scientific Conference on Information, Communication and Energy Systems and Technologies*: p. 231-234.

[28] Wu, J., Wu, G. d. and Wang, J.-l. (2017). Flexible job-shop scheduling problem based on hybrid ACO algorithm. *International Journal of Simulation Modelling (IJSIMM)*, **16**(3):497-505.

[29] Xu, H., Bao, Z. R. and Zhang, T. (2017). Solving dual flexible job-shop scheduling problem using a Bat Algorithm. *Advances in Production Engineering & Management*, **12** (1):5-16.

[30] Nouri, H. E., Driss. O. B. and Ghédira, K. (2018). Solving the flexible job shop problem by hybrid metaheuristics-based multiagent model. *Springer. J Ind Eng Int*, **14**:1-14.

[31] Gaham, M., Bouzouia, B. and Achour, N. (2018). An effective operations permutation-based discrete harmony search approach for the flexible job shop scheduling problem with makespan criterion. *Applied Intelligence*, **48**(6):1423-1441.

[32] Huang, M., Mingxu, W. and Xu, L. (2016). An improved genetic algorithm using opposition-based learning for flexible job-shop scheduling problem. *Cloud Computing and Internet of Things (CCIOT)*, 2016 2nd International Conference on: p. 8-15.

[33] Dziurzanski, P. et al. (2019). Solving the Multi-Objective Flexible Job-Shop Scheduling Problem with Alternative Recipes for a Chemical Production Process. *Applications of Evolutionary Computation - 22nd International Conference EvoApplications 2019. Lecture Notes in Computer Science*: p. 33-48.

[34] Gu, X.-L., Huang, M. and Liang, X. (2020). A Discrete Particle Swarm Optimization Algorithm With Adaptive Inertia Weight for Solving Multiobjective Flexible Job - shop Scheduling Problem. *IEEE Access*, **8**:33125 – 33136.

مشكلة جدولة عمل المهام : مراجعة الدراسات السابقة

مروة عبد الكريم العباسي ، أنفال عبد المنعم فاضل ، رشا غانم السراج

قسم البرمجيات ، كلية علوم الحاسوب والرياضيات ، جامعة الموصل ، الموصل ، العراق

الملخص

كامتداد لجدولة عمل المهام (JSP) ، فإن مشكلة جدولة عمل المهام المرنة (FJSP) يمكن تعريفها على أنها واحدة من أهم المشاكل في أنظمة التصنيع الحديثة. في الآونة الأخيرة ، أجريت العديد من الدراسات لمعالجة الـ FJSP . سوف يقدم العمل المعروض مراجعة للدراسات السابقة عن الـ FJSP. في البداية ، سيتم تعريف المشكلة ، وبعد ذلك ، سيتم تصنيف الدراسات السابقة على أساس الأساليب المختلفة التي تم استخدامها من عام 2010 لحل المشكلة. وأخيراً ، ستقدم بعض الاستنتاجات بناءً على نتائج المراجعة التي تم إجراؤها.