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Dr.Luma S.Hasan, contributed to Conceptualization, Methodology, and Supervision; Zainab A.Abdalhussain performed Data Curation, Formal Analysis, Writing – Original Draft and Visualization; Luma S.Hasan contributed to Review & Editing.

Data Availability

All data sets supporting the findings of this study are available in (M. Mastrolilli. Flexible Job Shop Problem. http://www.idsia.ch/~monaldo/fjsp.html)

REVIEW

A Review on Elitist Ant System Algorithm and Applications in Flexible Job Scheduling Problem

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Abstract

Scheduling is an important technique being used widely in numerous applications especially in industry. Flexible Job Shop Scheduling Problem (FJSP) is an extension of job scheduling which has several practical applications, (FJSP) is NP-hard combinatorial optimization problem. Owing to its importance and intricacy a lot of attention has been paid to this topic. Many swarm intelligent algorithms have drawn inspiration from nature; one particularly notable example is Ant Colony Optimization (ACO), which has shown to be incredibly successful and productive when applied to high-complexity (NP-hard) combinatorial optimization tasks. The paper presents a literature survey on ACO variants types and applications in Scheduling.

Keywords: Flexible job shop scheduling problem, Ant system, Elitist ant system, Swarm intelligence

1. Introduction

The job shop scheduling problem (JSSP), an NP-hard production scheduling problem, is one of the most well-known [1]. Each task is processed on machines with a specified processing time according to its production routine, and every machine is limited to perform a single operation per job [3]. JSP is NP-hard, and Flexible JSSP (FJSSP) is an extension of it. In contrast to the JSP, the FJSP allows for the selection of a set of machines for each operation, increasing scheduling complexity and flexibility. As a result, the JSP is simpler than the FJSP [4].

Inspired by the foraging habits of ants in ant colonies, (ACO) is a population-based metaheuristic solution for an optimization problem. The ants have the ability to navigate from their nest to a food source and back again by using the shortest path possible [5]. The elite ants, which might be one or more, are responsible for updating the pheromone trails, which sets the elitist ACO apart from the ACO [6]. In addition to providing a brief discussion of the FJSP and attempting to solve the problem using one of the swarm intelligent algorithms known as (EAS), this study addresses the current approaches to tackling the problem discovered in recent research.

The reminder of this paper is organized as following. Section 2 describes the flexible job shop scheduling problem, section 3 Optimization algorithm for scheduling, section 4 explain EAS and its applications, the related work introduce in section 5, Finally the Conclusion.

2. Problem description

Brucker and Schlie were the first who study the Flexible Job Shop Scheduling Model (FJSSP), using a polynomial technique to handle two jobs [14]. FJSSP because machines can be chosen for any or all operations, the model is more sophisticated and complex than JSP [7]. The FJSSP can be described as follows. There are a set of n jobs {1,2,3, $\cdots$ n} to be processed on m machines {1,2, 3, $\cdots$ m }.Each job i consists of a sequence of operation{$O_{i\ 1}$, $O_{i\ 2}$, $O_{i\ 3}$,… $O_{i\ si}$ } Each operation, can be processed by a subset $K_{i\ j} \subseteq K$, of eligible machines.

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Generally, FJSSP considers the following presumptions.:

1 Processes belonging to the same job must be completed in the specified order.
2 Different jobs operate independently from one to another.
3 At time zero, every work and every machine are available.
4 No machine can process more than one operation at a time, nor can one operation be conducted on many machines at once.
5 Every piece of machining data, including idle power, processing time, and machine power, is predetermined and deterministic.
6 There is a little difference across jobs at the same machine during setup periods and the travel times between machines.
7 No operation can be interrupted once an operation is started.

FJSSP seeks to reduce or maximize one or more scheduling objectives by rationally selecting the machine for every operation and figuring out a work order on every machine. In traditional shop scheduling, the only thing that needs to be decided is the order of operations on each machine because each machine is unique for every task. Additionally, resource uniqueness is eliminated by variable job shop scheduling, allowing jobs to be completed on several machines for each operation. Not only the operation must be sequenced, but choices must also be made on the machinery that will process the operation [11]. There are several other types of flexibility in the actual manufacturing process, including Flexibility in process sequence, machine selection, and other areas [8].the two sub-problems for FJSSP are:

➢ Each operation is assigned to the proper machine via the operations assignment sub-problem.
➢ The sub-problem of operations sequencing establishes a sequence of actions for each machine [9].

Total FJSP (also known as T-FJSP) is the term used when every machine can be selected for the procedures. Part FJSP is what's known when only a few selected machines are available for using in the operations (P-FJSP) [7]. The partial machine chose flexible scheduling problem which is more appropriate for real-world production contexts than the whole flexible scheduling problem for machine selection. However, Compared to the entire machine selection flexible scheduling problem, the partial machine selection flexible scheduling problem has a larger search space, a more difficult solution, and a greater computing complexity [8]. The Table 1, 2 shows the difference between the two cases.

3. Optimization algorithm for scheduling

The challenge of scheduling is crucial to many industrial systems [13]. Conventional problems like JSP, FJSSP, and MpFJSSP concentrate on semi-distributed scheduling problems that can be handled using either a mono- or multi-objective optimization approach.There are two primary categories of schedule optimization algorithms: exact optimization methods and approximation ones. Precise optimization strategies include effective rule approaches, mathematical programming approaches, branch definition methods, and others. Local search, metaheuristic algorithms, artificial intelligence, and constructive techniques are among an approximative techniques. Each technique is further broken into algorithms. As shown in Fig.(1)Since the initial issue may be divided into several smaller, better controlled, related sub-problems that can all be addressed independently, we can solve the sub-problems more quickly and effectively with mono/multi-objective optimization algorithms than we could with a concentrated scheduling problem [7].

4. Elitist ant system

The optimization technique known as "ant colony optimization" originated from the behavior of ant

Table 1. Simple instance of the P-FJSP.

Job	Operation	M1	M2	M3	M4	M5
J_1	$O_{1,1}$	2	9	4	5	1
	$O_{1,2}$	–	3	–	2	–
J_2	$O_{2,1}$	2	4	–	–	6
	$O_{2,2}$	1	–	3	–	–
	$O_{2,3}$	–	4	–	5	4
J_3	$O_{3,1}$	4	2	–	–	1
	$O_{3,2}$	–	6	1	4	–
	$O_{3,3}$	–	9	3	–	7

Table 2. Simple instance of the T-FJSP.

Job	Operation	M1	M2	M3	M4	M5
J_1	$O_{1,1}$	2	9	4	5	1
	$O_{1,2}$	4	3	7	2	8
J_2	$O_{2,1}$	2	4	8	3	6
	$O_{2,2}$	1	1	3	4	1
	$O_{2,3}$	9	4	3	5	4
J_3	$O_{3,1}$	4	2	4	6	1
	$O_{3,2}$	9	6	1	4	2
	$O_{3,3}$	1	9	3	2	7

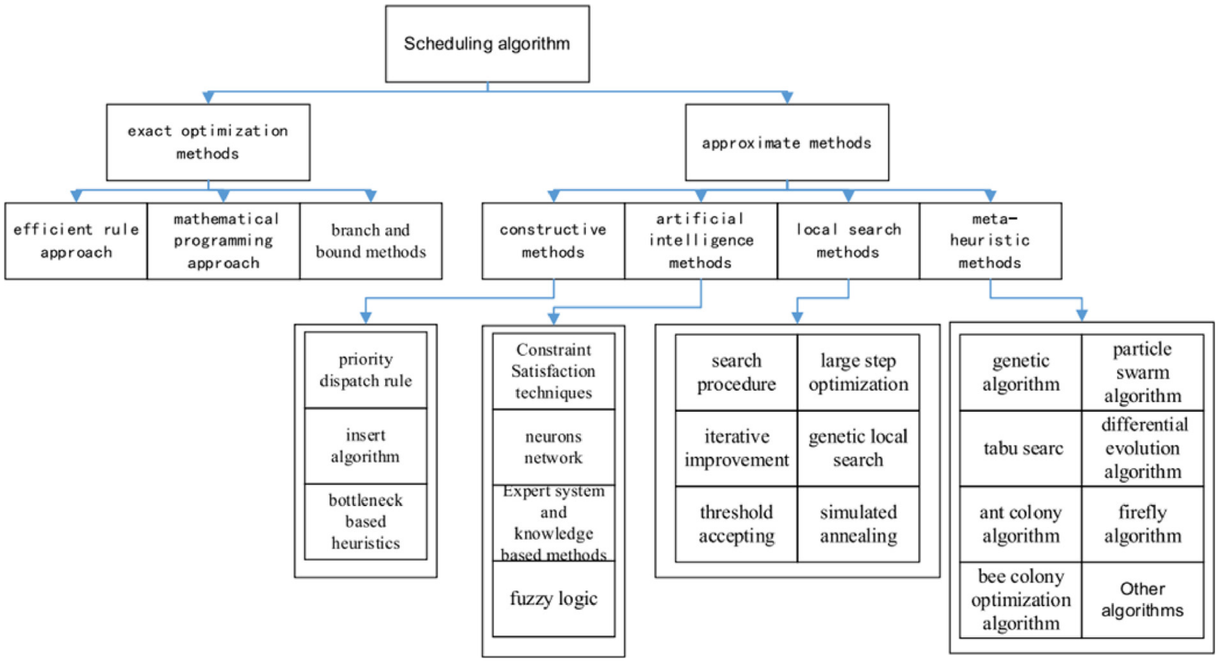

Fig. 1. categories of schedule optimization algorithms.

colonies and it is based on the best-found path towards a workable solution using traces of pheromones left by simulated ants [2].ACO is one kind of algorithm that is utilized in reinforcement learning. An ants in ACO use pheromones and heuristic knowledge to make probabilistic decisions when constructing a feasible solution. When addressing a problem, the selection probability distribution was used to identify the next site is crucial [10]. Ants usually start off by aimlessly looking for food in their surroundings and bringing some of it back to their nest. They leave pheromone fluids on the trail they found, The worth of the pheromones, they leave behind which gradually evaporate, depends on the quantity and caliber of food available [12].

The Fig. 2 shows the behavior of ants in nature, as they initially search randomly for the target (the food's source), and during that time, the ants spray a chemical substance so that the rest of the ants can follow it. Ants leave behind a pheromone to identify their routes as they go from point A (the source) to point B (the destination). This makes it easier for the ants that follow to locate their fellow ants as they sense pheromone and, more often than not, select trails with higher pheromone concentrations. Fig. 3 illustrates the technique, which is based on adaptively modifying the pheromone on routes at each node. This node's selection is determined on using a probability-based selection methodology [33].

There are some of the most popular variations of ACO algorithms.

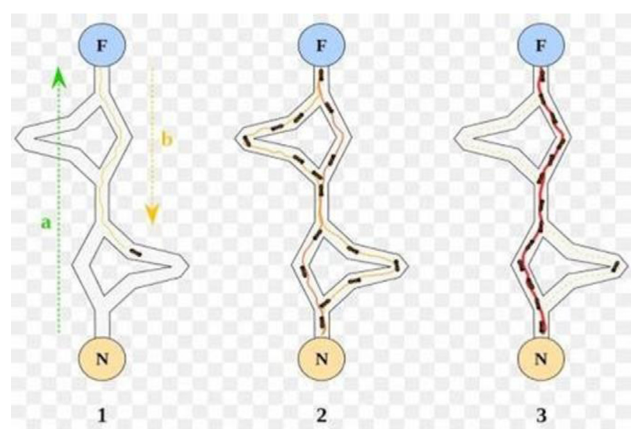

Fig. 2. Behavior of ants in searching for food.

- Ant System (AS)
- Ant Colony System (ACS)
- Elitist Ant System (EAS)
- Max-min Ant System (MMAS)
- Parallel Ant Colony Optimization (PACO)
- Recursive Ant Colony Optimization (RACO).
- Rank-based Ant System (ASrank)

An Ant System variation which is presented in this article, is Elitist Ant System(EAS), also proposed by Dorigo as an improvement to SH [15]. The algorithm uses a global best solution to deposit pheromone on its trail after every iteration, including all other ants. The elitist strategy aimed at improving the convergence speed and solution

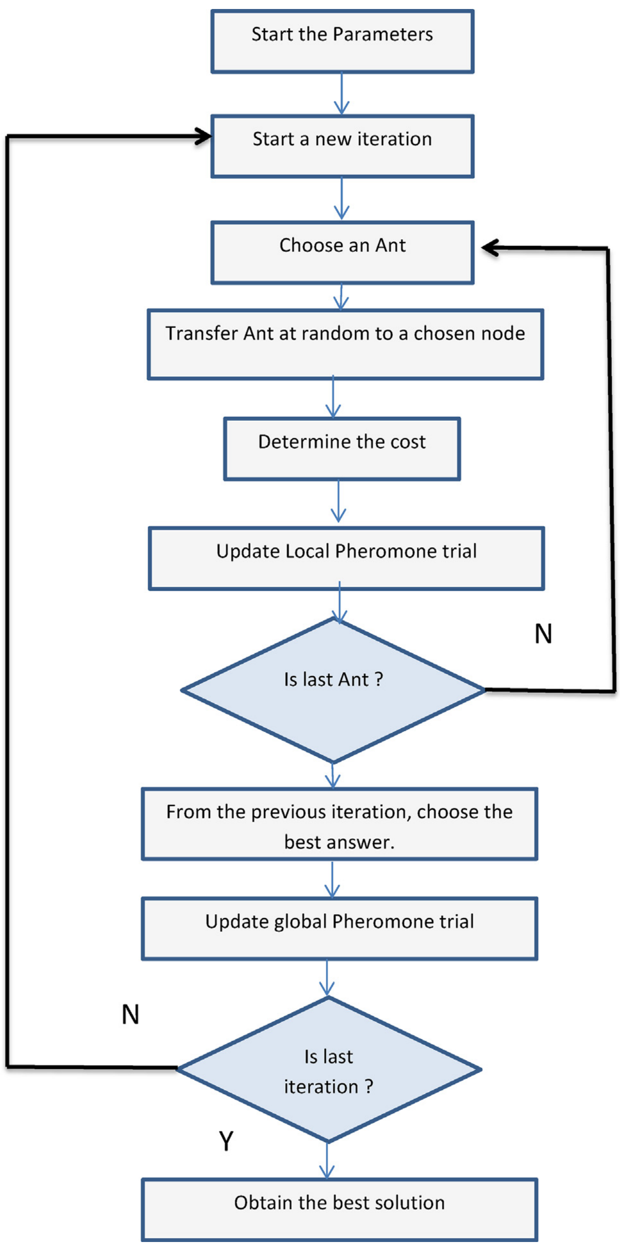

Fig. 3. probability-based selection methodology (ACO Algorithm).

quality, The state transition and the pheromone update model influence the ACO algorithm's convergence rate and forecast accuracy [17]. Ants produce a set amount of pheromones when foraging, and under the positive feedback, all ants will progressively migrate toward their own unique optimal solution [16].

The ant-cycle, ant-quantity, and ant-density models are the three primary components of the ACO algorithm's pheromone update model. The ant-cycle model is a global pheromone update approach in which each individual ant's pheromone is updated subsequent to the population's position data being updated. The local update technique uses ant-quantity and ant-density models, and each iteration updates the pheromone concentrations of the individual ants. In the ant-density model, the pheromone concentration is a fixed value, whereas in the ant-quantity model, it is correlated with the starting parameter. The transfer probability equation of Eq. (1) in EAS [18].

$$p_{ij} = \frac{(\tau_{ij})^{\alpha}(\eta_{ij})^{\beta}}{\sum_i (\tau_{il})^{\alpha}(\eta_{il})^{\beta}} \tag{1}$$

where:

ηij, the heuristic information or visibility of arc (i, j), is the inverse of the distance between node i and node j: i.e.

$$\eta_{ij} = 1/d_{ij} \tag{2}$$

The node's pheromone values are updated when the solutions are constructed. There are two stages to the upgrade. The algorithm applies an evaporation rate ρ, with ρ ∈ [0, 1], to the pheromone at each node just before the ants can deposit pheromone in the node of their solution see Eq. (3):

$$\tau_{ij}(t) = (1-\rho)\cdot\tau_{ij}(t) \tag{3}$$

As the ants finish building their paths, Eq. (4) must be used to update the pheromone values since each marching ant leaves behind some extra pheromones.

$$\tau_{ij} = \tau_{ij} + \sum_{k=1}^{m} \Delta\tau_{ij}^{k} \tag{4}$$

where: τ_{ij} is pheromone value, ρ is evaporation coefficient of pheromone. $\Delta\tau_i^k(t)$ is the quantity of pheromone on the node (i, j) laid by ant k and can find it by (Q/L_K).

In order to hasten the algorithm's convergence, make the pheromone trail more visible on all of the shortest path's edges and pass all of the system's elitist ants (e). Therefore, the equation (3) for the best path built in each cycle is replaced by the Eq. (5):

$$\Delta\tau_{ij}^{k} = \left(\frac{Q}{L}\right) * e \tag{5}$$

Each ant put a pheromone, then will modify the pheromone value on the passed node by applying the local updating rule, as follows in Eq. (6), Once all ants have arrived at their destination, the value of pheromone on the node is modified again by applying the global updating rule, as shown in Eq. (7):

$$\tau_{ij}(t) = (1-\rho)\cdot\tau_{ij}(t) + \rho\tau_0 \tag{6}$$

$$\tau_{ij}(t) = (1-\rho)\cdot\tau_{ij}(t) + \rho\Delta\tau_{ij}k(t) \tag{7}$$

4.1. Practical applications

The Elitist Ant System, like the basic Ant Colony Optimization, can be applied to a variety of combinatorial optimization problems, including the Traveling Salesman Problem (TSP), Job Scheduling, and Routing Problems, as show in Table 3 the introduction of the elitist strategy which is expected to enhance the algorithm's performance in finding high-quality solutions [33].

Table 3. An incomplete compilation of effective algorithms for optimizing ant colonies.

No.	Problem type	Problem name
1	Routing	1- Traveling salesman (TSP) 2- Sequential ordering 3- Vehicle routing 4- Optical network routing
2	Assignment	1- Quadratic assignment 2- Frequency Assignment
3	Scheduling	1- Project scheduling 2-Car sequencing
4	Bioinformatics	1-Protein folding 2-DNA Sequencing
5	Machine learning	1-Classification rules 2-Fuzzy Systems 3- Neural networks

5. Related work

Shaofeng Yan 1 et al [11]. in 2023 presented an improved ant colony optimization approach to tackle the flexible job shop scheduling problem with numerous time restrictions.The approach is tested on benchmark examples to show how well it solves the issue. It combines a number of strategies, including distributed coding, diversity improvement, local search, filtering, and initialization techniques. The algorithm was evaluated through experiments based on 28 benchmark instances, and the experimental results showed that it can effectively solve the MaOFJSP problem.

Ojstersek et al [19] The study evaluated a multi-objective Kalman algorithm (MOHKA) using a Flexible Job Shop Scheduling Production Optimization problem. Results show MOHKA can solve complex optimization problems, overcoming commercial simulation software's integrated decision logic. It compares MOHKA results with MOPSO and BBMOPSO.

Aleksandar et al [20]. The Flexible Job Shop Planning (FJSSP) problem is a scheduling challenge with machine-dependent processing time. A model using metaheuristic algorithms, Genetic algorithm, Tabu search, and Ant colony optimization, is presented demonstrating efficiency and graphic representation on a Gantt chart.

Zhenwei et al [21].Introduced a new shuffled cellular evolutionary grey wolf optimizer (SCEGWO) to solve the flexible job shop scheduling problem (FJSSP-JPC) and minimize makespan. SCEGWO encodes schedule solutions as triple-vectors, ensuring limitations on job priority are met through a binary sort tree-based repair mechanism. The algorithm decomposes the population into multiple subpopulations, allowing for communication by the neighborhood overlapping. The paper aims to develop an efficient metaheuristic optimization algorithm to tackle the NP-hard problem of flexible job shop scheduling in the manufacturing industry.

Haoliang Jin *et al.* [22] The multi-objective flexible job shop scheduling problem (MOFJSP) under dynamic perturbations is addressed in this research using an enhanced discrete particle swarm optimization technique (IDPSO). In order to improve the discrete particle swarm algorithm's capacity to leap out of local extremes, the authors combine the concept of variable neighborhood search (VNS) to create three neighborhood structures. The Kacem dataset is used to confirm the algorithm's efficacy. To address the FJSP problem and minimize completion time, total machine load, and critical machine burden.

Sura Mazin Ali *et al.* [23] they discussed the use of the Artificial Fish Swarm Algorithm (AFSA) enhanced with diversity operators (AFSA-DO) in order to resolve the (FJSSP). The enhanced algorithm showed improvements in solution quality and intersection rate compared to the original AFSA. However, it may face drawbacks such as complexity of settings, time performance, dependency on diversity, and difficulty handling large-scale problems. These drawbacks should be considered when using AFSA-DO for optimal results.

Rakesh Kumar *et al.* [24], they discussed the Coco Sparrow Search (CSO) algorithm, a bird search method, for flexible work scheduling in workshops. The CSO algorithm, inspired by sparrows' egg-laying and reproductive systems, is used to solve complex optimization problems. A CSO technique based on simulation is suggested to address the flexible workshop scheduling issue, using

PROMODEL© software to model the store and measure total production time. The results show that the simulation-based CSO algorithm effectively improves the problem.

Zhang et al. [25] proposd an improved genetic algorithm to minimize Flexible Job Shop Scheduling Problem (FJSP) in factory scheduling. The algorithm uses crossover method, artificial pairing, and adaptive weight mechanism, enhancing population diversity and performance in experiments.

Torres-Tapia et al. [26] propose a hybrid algorithm for globalized production systems, focusing on flexible job shop scheduling and vehicle routing. The metaheuristic procedure solves the combined scheduling-routing problem, emphasizing the importance of integrating production and transportation activities for customer demand and logistics cost optimization. Experiments were carried out by adapting the datasets from Hurink (1994).

Guohui et al. [27] addresses the Flexible Job Shop Scheduling Problem (FJSP) by introducing an improved genetic algorithm to address the issue of transportation time. The proposed genetic algorithm minimizes the maximum completion time and solves the actual instance using Matlab software. The computational results show the proposed mathematical model and algorithm are valid and feasible, potentially guiding production practice. The paper also addresses promising research directions and discusses the problem's assumptions and potential research directions.

Van Hentenryck *et al*. [28] The study presents two-stages of learning framework, 2SL-FJSP, which models hierarchical FJSP decisions, generates scheduling instances, and addresses uncertainty in day-of-operation, outperforming traditional heuristics and reinforcement learning in experimental settings.

Mao C. L. [29] introduces an improved particle swarm optimization (PSO) for managing multi-objective flexible job-shops under various conditions. It improves inertial weight, learning factors, global and local search functionality, and presents a dynamic system of reaction. This paper addresses an increasing demand for diverse products.

Bekkar et al. [30]. proposed two greedy heuristics based on an iterated insertion technique to solve the problem with the constraint of transportation time between machines.

Zhang et al. [31]. To solve the MOFJSP, which aims to minimize the longest makespan of work pieces, the load of each machine, and the total machine load, they created a multi-population GA.

Jiang et al [32].explored the use of grey wolf optimization (GWO) algorithm in solving combinatorial problems in manufacturing, specifically job shop scheduling. Inspired by grey wolves' social hierarchy, the discrete GWO algorithm outperforms other meta-heuristics.

6. Conclusion

This paper presents a review of a previous research related to metaheuristic algorithms and (AS) as ACO and its application in solving scheduling problems. EAS is a variant type of ACO that is used for the first time to solve the flexible scheduling problem by modifying the local update and global update pheromone equation. In this algorithm we used a number of elite ants to speed the convergence to reach to the optimal solution. This modification leads to become popular algorithm to solve many NP-hard optimization problems.

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