**A Brief Review of Various Meta-Heuristic Optimization Algorithms for Scheduling Issues**

**Abstract**

Scheduling plays a vital role in various organizations and industrial sectors, ensuring the efficient allocation of tasks to available resources. However, real-world scheduling problems are often complex due to their large scale and numerous constraints. The traditional optimization methods frequently struggle to provide effective solutions for these challenges, necessitating more advanced approaches. In order to address these challenges, meta-heuristic algorithms have been developed, offering powerful techniques for finding optimal or near optimal solutions in complex scheduling scenarios. This study presents a detailed review of existing meta-heuristic algorithms for scheduling problems and highlights their applications across various fields, including manufacturing and production, information technology. The effectiveness of scheduling has been greatly enhanced by utilizing the advantages of diverse meta-heuristic algorithms, making them more suitable for a wide range of applications.

***Key words:***  *Job Scheduling. Optimization Algorithm****.*** *Meta-Heuristics*

1. **Introduction**

Job scheduling is an important activity in every industrial sector. It is a process that is associated with allocation of resources to machines to perform some tasks with a given time. Resources can refers to a wide range of assets, including machines, people, equipment, and other items that can are used to complete tasks and these tasks could include manufacturing processes, airline flights, construction projects, and computer processes, among others (Phanden *et al*., 2012). The major goal of job scheduling is to maximize the efficiency of the system by ensuring that resources are used in an optimal way. This can involve considering factors such as the priority of the job, the availability of resources and the estimated runtime (makespan). Job scheduling could be trace back to the work of Johnson (1954) were he proposed an algorithm for a two machine problem and various optimization algorithm has been developed over the years for handling scheduling problem.

Optimization algorithm is mathematical algorithm that is designed in a way to find the best solution to a given problem. Optimization algorithm involves selecting the best solution from a set of available options based on a specific criterion (Handibag & Sutkar, 2021). Optimization algorithms are used to solve a problem by using a series of steps that lead from the initial solution towards the optimal one.

Meta-heuristic algorithm is a computational intelligence method that is particularly useful for solving complicated optimization problem (Abdel-basset *et al*., 2018). Meta heuristic algorithms are a class of optimization algorithms that use randomization and heuristics to find approximate solutions to complex problems and these algorithms often based on mimicking natural processes such as evolution, genetics or swarming to find optimal solutions.

1. **Statement of the Problem**

Job scheduling becomes more complex as the number of jobs and machines increase and scheduling becomes an extremely difficult task (Tsetimi, 2010). These types of problem are classified as non-polynomial-hard (NP) problem and hence there are no exact methods available and flexible to solve for such problems. However, meta-heuristics algorithms are used to find near-optimal solutions that can be used to schedule tasks in such way that minimizes some objective function, such as the total completion time. A systematic approach, based on pre-defined guidelines was used to review the literature on meta-heuristic algorithms to job scheduling problems. The guidelines provide a reliable overview of the existing evidence on two major meta-heuristic algorithms; Genetic algorithm and Particle swarm optimization

**3. Optimization Problem and Meta-Heuristics Algorithms**

Meta-heuristic algorithm is a class of algorithm that is developed for solving complex optimization problems. It is a high level approach that can be used with different algorithm and problem solving techniques. Radhika and Chaparala (2018) described meta-heuristic as an iterative process that is modified and guides the operations of other heuristic algorithms in order to produce efficient high quality results and are designed in such a way that they suits any problem. Meta heuristic algorithms are typically used when there is no know efficient algorithm for solving the problem or when the problem is NP-hard. Meta-heuristic algorithms are not specific to a particular problem, but they are general strategies that can be applied to a wide range of problems (Toaza and Esztergar-Kiss, 2023). According to Almufti *et al.*, (2023), meta-heuristic are used to describe a process that can search, fine, crate high quality solutions to optimization problems particularly those that are large or difficult to solve. They can be used to solve a variety of different problems, as long as the problem can be represented on terms of a search space and an objective function. The Meta heuristics are used extensively to find near-optimal solutions to difficult and complex optimization problems, which are regarded as NP-hard problem (Peres and Castelli, 2021). Unlike other algorithms that follows a specific set of steps to find the solution to the problem, meta heuristic algorithm use a more general frame work to explore the solution space and select the optimal solution. Over the years different meta-heuristics algorithms have been developed, each having its sets of strengths and weaknesses. The following are some of the most widely used meta-heuristic algorithms.

**3.1 Genetic Algorithm (GA):** The genetic algorithm is an optimization that mimics the natural selection process in biological evolution (Katoch *et al*., 2020). According to Alshattnawi *et al*. (2021), GA is evolutionary algorithm that is effective for solving complex optimization problem. The algorithm was first introduced in the work of Holland, (1975) which was titled “Adaptation in Natural and Artificial System”. According to Kaur and Chhabra (2019), GA is search and optimization technique based on population, which means they have a set of possible solution. They are based on Charles Darwin’s theory of evolution which says that populations change and adapt over time through natural selection. GA starts with a group of possible solutions called chromosomes, where each chromosome represents a possible solution to the problem(Almufti *et al*., 2019). GA, uses a population of solutions called chromosomes and a fitness to evaluate the quality of each solution. Then after, uses genetic operators such as crossover and mutation to create new solutions from the best solutions in the population. Over time, the process converges to a solution that is optimal or near-optimal for the given problem as shown in figure 1.

Start

Generate the population of individuals (chromosomes)

Evaluate each chromosome using a fitness function

Choose the fittest chromosomes to breed the next generation

Stopping Criteria

NO

Combine the selected chromosomes to create new offspring

Stop

Figure 1: Procedures of PSO (Almufti *et al*., 2019)

YES

Select optimal solution

Randomly change parts of the chromosomes to introduce diversity into the population

**3.2 Particle Swarm Optimization (PSO):** This algorithm was proposed by Kennedy and Eberhart in the year 1995. This is a swarm intelligence algorithm that is inspired by the social behavior of fish or birds (Tran, 2018). PSO is a computational technique that uses a series of small improvements to candidate solutions by using a given fitness function (Pradhan, 2022). This is done by comparing the fitness of each candidate solution to the fitness found so far and adjusting the position of each solution based on the comparisons. The goal of the PSO is to find optimal solution by having a population of particles (or potential solutions) collaborate and share information. Each particle is a member of the population and the entire population is called the swarm. According to Pradhan (2022), a particle swarm needs to explore the search space in order to find promising regions and each particle has its own position and velocity which starts out with a random position. He also went further to say that each particle has its own personal position known as the P-best and the best position found by the entire swarm (G-best). Fig.2 shows procedures of PSO (Tran, 2018)

Fig.2 Procedures of PSO (Tran, 2018)

Select the optimal Solution from the Pareto Set

Start

Initialize the population of the Particle

Evaluate each Particle in the Swarm

Calculate the Particle’s Fitness using the objective function

Calculate the Personal and Global Best Position (P-best and G-best) for the Entire Population

Create the Pareto Set

Stop

NO

Check to see if all the Iterations have been completed

YES

1. **Review of Meta-Heuristic Algorithm on Scheduling Problem**

Generally, the goal of a scheduling problem is to find near-optimal solutions that optimize the objective function. Various Meta heuristic algorithms have been applied to wide range of scheduling problem which include the flow shop, job shop, cloud scheduling

* 1. **Scheduling Based on Genetic Algorithm**

Genetic optimization algorithm has been used across a wide range of scheduling problem. Hamdi and Tekaya (2019) presented a six version of genetic algorithm based on different genetic procedures to minimize the makespan in a two machine cross-docking flow shop scheduling problem. Manjeshwar *et al*. (2011) developed a genetic algorithm approach to minimize the total completion time for two batch processing machines in a flow shop. Singh *et al*. (2019), presented a genetic algorithm to obtain optimal solutions for grid task scheduling. They try to minimize the time taken for all tasks to be completed and the total time spent by each task in execution (flow-time), while ensuring that the workload is evenly distributed across all computing agents. Salido *et al*. (2016) proposed a genetic algorithm to treat an extended version of a job scheduling problem were the machines can use different amount of energy to process tasks at different rates. Luo *et al.* (2020) presented an improved genetic algorithm for flexible job shop scheduling problem. The algorithm incorporated a new generation mechanism in order to produce the initial population, which help to improve the convergent speed of the algorithm. A modified genetic algorithm that incorporates scheduling principles was presented in Amjad *et al.* (2021) for flexible job shop scheduling problem. The proposed method employed an adaptive technique for the crossover and mutation probabilities in order to maintain a maximum search space evaluation.

**4.2 Scheduling Based on Particle Swarm Optimization (PSO)**

Over the years, PSO has undergone many variation and modifications. Abdullah (2018), presented a solution to job shop scheduling problem using a modified PSO algorithm. The system used the developed PSO as the search method to obtain the optimal time. The improved technique is used to fix the residual position of the particles and is focused on keeping the particles from being placed in an idle location. Ravichandran *et al.* (2016) employed GA and PSO to solve job shop scheduling problem in parallel line with the aim of minimizing the total completion time (makespan). A comparative of the makespan of GA and PSO was presented and the results show that the PSO gives best optimal solution for makespan minimization. Nzanywayingoma and Yang, (2017) combined the PSO and GA to solve task scheduling problem in cloud computing. The authors gave a comparative analysis in order to prove the efficiency of the PSO and GA with respect to execution time and processing cost. Shao *et al.* (2023) proposed an algorithm for scheduling in cloud computing. The algorithm integrated the GA into PSO with the aim to satisfy the user and optimize the resource efficiency. The algorithm was successfully used to solve the problem by combing the advantages of GA and PSO. In 2023, Zhang *et al*. proposed an improved multi-phase Particle Swarm Optimization algorithm to solve the dynamic job shop scheduling problem, their algorithm integrates a cellular neighbor network, a velocity reinitialization strategy and a constraint-handling function to enhance its optimization performance. Their results demonstrated superiority when tested on the Kundakci and Kulak problem and compared with the original multi-phase Particle Swarm Optimization and the Heuristic Kalman Algorithm.

* 1. **Scheduling Based on Other Meta-heuristics**

Benni *et al*. (2024) evaluated the performance of three meta-heuristics algorithm; simulated annealing, Artificial Bee Colony, and Tabu Search in addressing job scheduling problem. They focused on minimizing of makespan, machine idle time and production cost. Maduku and Tsetimi (2024), presented a heuristic algorithm for job scheduling problem in multiple machine problem based on the Johnson’s algorithm. The study used the makespan and machine idle time minimization benchmark criteria. Jomah and Aji (2024), explores meta-heuristics with focus on swarm intelligence-based algorithms for cloud computing. It examines how hybrid approaches leveraging diverse meta-heuristic techniques enhance scheduling performance. It further provided a comparative analysis of different meta-heuristics algorithms, computing environments, simulation tools, scheduling objectives and performance metrics.

Meta heuristic algorithms can be more effective if multiple algorithms are combined to generate optimal solutions; by combining, the strengths of different algorithms, it is possible to achieve better results than when using a single algorithm (Kaur and Chhabra, 2019).

**5.0 Summary of Reviewed Meta-Heuristics Algorithms on Scheduling Problem**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Year** | **Algorithm** | **Area** | **Objective** | **Finding** |
| **Hamdi and Tekaya (2019)** | Genetic Algorithm | Flow shop scheduling | Minimize makespan | The GA demonstrated improvement in minimizing makespan |
| **Manjeshwar *et al*. (2011)** | Genetic Algorithm | Flow shop with batch processing machines | Minimize total completion time | The method prove effective in reducing processing time and overall efficiency |
| **Singh *et al*. (2019)** | Genetic Algorithm | Grid task scheduling | Makespan minimization | The GA approach provided a substantial improvement over conventional methods in handling the complexities of task scheduling in grid computing |
| **Salido *et al*. (2016)** | Genetic Algorithm/ Simulated Annealing | Job shop scheduling problem | Minimization of makespan | Combining of constraint satisfaction methods can significantly enhance the efficiently and flexibility of solving complex scheduling problems |
| **Amjad *et al.* (2021)** | Genetic Algorithm | Flexible job shop scheduling | Improve computational effectiveness | The combination of metaheristic approach with exact methods allows for balancing exploration and exploitation in the search space. |
| **Luo *et al.*, (2020)** | Genetic Algorithm | Flexible job shop scheduling | Improve computational speed | The method demonstrated significant improvements in minimizing the makespan and enhancing resource utilization |
| **Abdullah, 2018** | Particle Swarm Optimization | Job shop scheduling problem | Minimize makespan | The developed algorithm was able to over the idle particle position |
| **Ravichandran *et al.*, (2016)** | Genetic Algorithm / Particle Swarm Optimization | Job shop scheduling in parallel line | Minimize makespan | Optimization algorithms yield the best solutions for parallel line job shop scheduling when job quantities are considered. They can handle combination of lines, jobs and machines, providing the minimum makespan along with the corresponding job sequence |
| **Nzanywayingoma and Yang, (2017)** | Particle Swarm Optimization / Genetic Algorithm | Cloud computing | Optimize total completion time and processing cost | Combining PSO and GA dramatically reduces the task execution time and computation cost |
| **Shao *et al.*, (2023)** | Genetic Algorithm / Particle Swarm Optimization | Cloud computing | Optimize resource efficiency and user satisfaction | The results shows that the hybrid algorithm perform excellently. |
| Zhang *et al*. 2023 | Particle Swarm Optimization | Dynamic job shop scheduling problem | Machine processing time, machine utilization and machine operational cost. | It provides super converging rate while maintaining their performance |
| Maduku and Tsetimi (2024). | Johnson’s Heuristic | Multiple machine problem | Makespan minimization | It provides a significant performance in terms of total completion time and machine idle time |
| Benni *et al*. (2024) | Simulated annealing, Artificial Bee Colony, and Tabu Search | Job scheduling problem. | Minimizing of makespan, machine idle time and production cost. | It work demonstrated outstanding performance with the developed meta-heuristic algorithms |
| Jomah and Aji (2024) | Swarm intelligence Algorithm | Cloud computing |  | It shows that scheduling performance improves by the usage of various meta-heuristic |

**6.0 Conclusion:**

The complexity of scheduling problems tends to increase as the number of jobs and machines involves increases. This is because the search space becomes larger and there are more possible combinations of solutions to consider. The traditional optimization methods are not always effective for solving complex optimization problems. Meta heuristic algorithms can be more effective in finding optimal or near-optimal solutions.

Meta heuristic algorithms generally start with a population of random solutions, which are then iteratively optimized using a set of operators. All meta-heuristic algorithms have common elements to create and evaluate the solutions. However, different meta-heuristics uses different approaches to implement these elements. The appeal of using meta-heuristic algorithm for complex scheduling problem is that they obtained optimal solution even for a very large size problem in a short computation time.

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