A Survey of Some Meta-Heuristics Optimization Algorithms for Scheduling Problems

Abstract

Scheduling is plays an essential role in every organization or industrial section. The process of allocating tasks to available resources can be very complex and difficult in many real world scheduling problem due to the large size of the problem. The traditional optimization methods are often limited in their ability to solve complex optimization problem. These types of problem require more sophisticated algorithms to find optimal solutions. Therefore, meta-heuristic algorithms have been developed to address these limitations and improve the efficiency of optimization. This study gave detail review of some existing meta-heuristic algorithms for scheduling problem.

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.

2. 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.

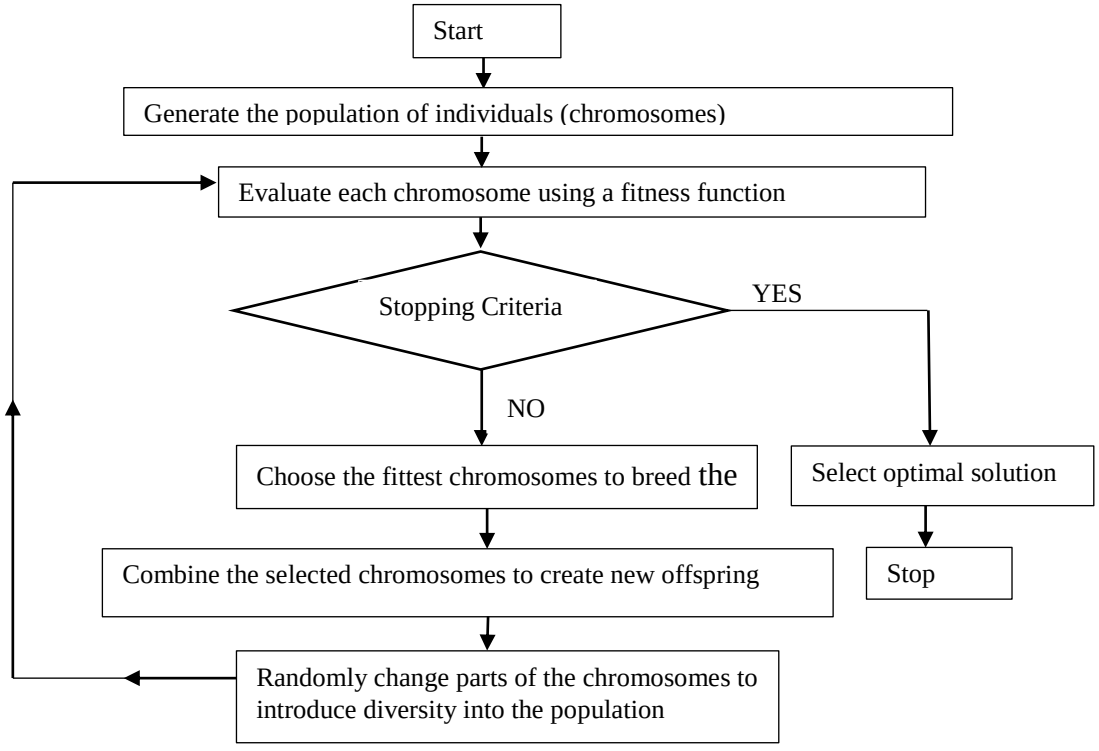

Figure 1: Procedures of PSO (Almufti *et al*., 2019)

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)

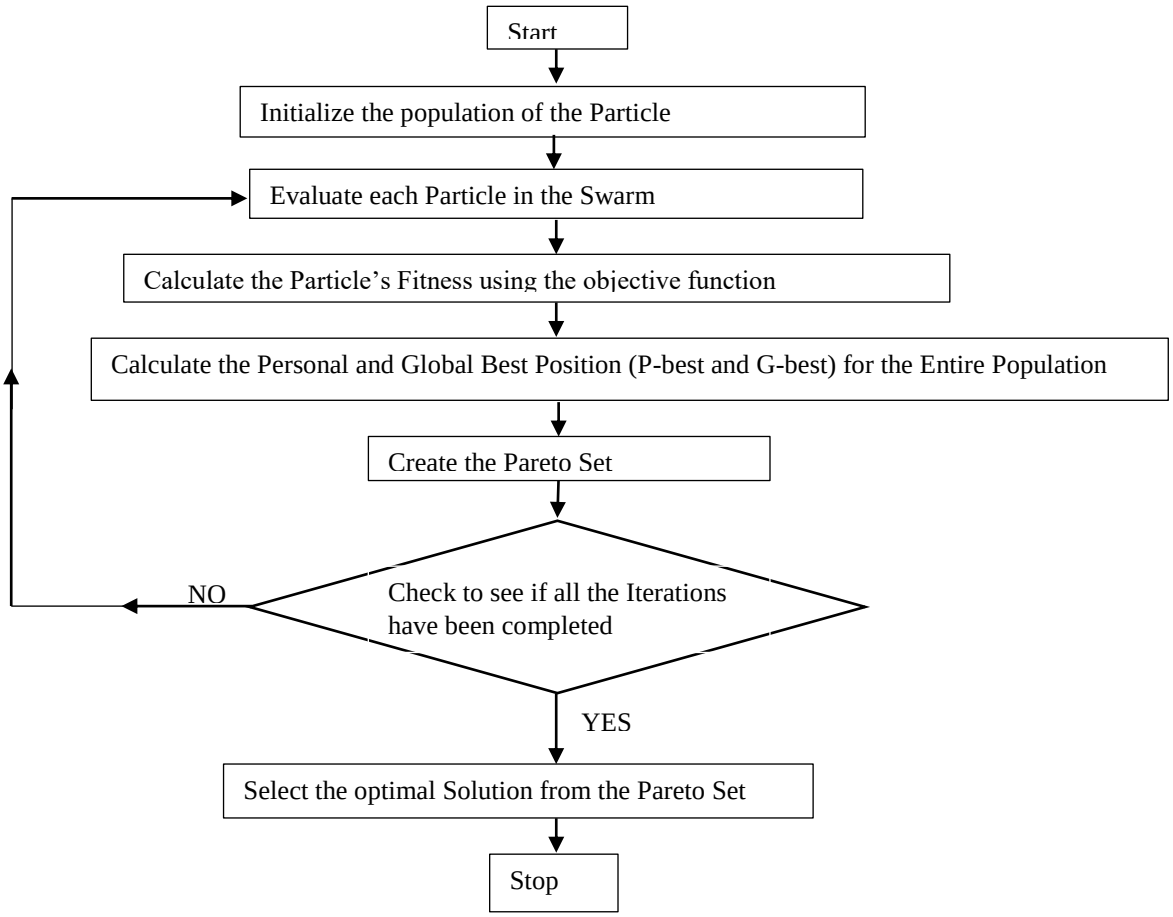

Fig.2 Procedures of PSO (Tran, 2018)

4. 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

4.1 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.

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/	Job shop scheduling	Minimization of makespan	Combining of constraint satisfaction

	Simulated Annealing	problem		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.

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.

References

Abdel-Basset, M., Abdel-Fatah, L. & Sangaiah, A.K. (2018). Metaheuristic Algorithms: A Comprehensive Review. Computational Intelligence for Multimedia Big Data on the Cloud with Engineering Apllications, 285-231. https://doi.org/10.1016/B978-0-12-813314-9.00010-4

Abdullah, W.N. (2018). Solving Job-Shop Scheduling Problem using a Developed PSO Algorithm. *International Journal of Science and Research, 7(1):1845-1848.* Dio: 10.21275/ART20179752.

Almufti, M.S., Zebari, A.Y. and Omer, H.K. (2019). A Comparative Study of Particle Swarm Optimization and Genetic Algorithm. Journal of Advanced Computer Science & Technology, 8(2):40-45. https://doi.org/10.14419/jacst.v8i2.29401

Almufti, S.M, Shaban, A.A., Ali, R.I. and Fuente, J.A.D. (2023). Overview of Metaheuristic Algorithms. Polaris Global Journal of Scholarly Research and Trends, 2(2): 10-32. https://doi.org/10.58429/pgjsrt.v2n2a144

Alshattnawi, S., Khraisat, R. and Majdalawi, H. (2021). Meta-heuristics Algorithms for Task and Workflow Scheduling in Cloud Computing Environment: An Overview. Acta Scientific Computer Sciences, 3(3): 02-10.

Amjad, M.K., Butt, S.I. and Anjum, N. (2021). Improved Genetic Algorithm Integrated with Scheduling Rules for Flexible Job Shop Scheduling Problems. E3S Web of Conferences. https://doi.org/10.1051/e3sconf/202124302010

Hamdi, I. and Tekaya, M.F. (2019). A Genetic Algorithm to Minimize the Makespan in a Two-Machine Cross-Docking Flow Shop Problem. Journal of the Operations Research Society of China, https://doi.10.1007/s40305-019-00277-6

Handibag, S. and Sutkar, P.S. (2021). Optimization Algorithms and their Applications. Malaya Journal of Matematik, 9(1):1006-1014

Holland, J.H. (1975). Adaptation in Natural and Artificial Systems. University of Michigan Press.

Johnson, S.M. (1954). Optimal two and Three Stage Production Schedules with Set-Up Time Included. *Naval Research Logistics Quarterly*, 1:61-68.

Katoch, S., Chauhan, S.S. and Kumar, V. (2020). A Review on Genetic Algorithm: Past, Present and Future. Multimedia Tools and Applications, 80:8091-8126, https://doi.org/10.1007/s11042-020-10139-6

Kaur, A. and Chhabra, A. (2019). Comparative Analysis between Different Meta Heuristic Algorithms for parallel Job Scheduling. Think India Journal, 22(30):143-154.

Kennedy,J. & Eberhart, R. (1995). Particle Swarm Optimization. Proceedings of ICNN-International Conference on Neural Networks, 1942-1948. https://doi.org/10.1109/ICNN.1995.488968

Luo, X., Qian, Q. and Fu, Y.F. (2020). Improved Genetic Algorithm for Solving Flexible Job Shop Scheduling Problem. Procedia Computer Science, 166:480-485.

Manjeshwar, P. K., Damodaran, P. and Srihari, K. (2011). Genetic Algorithms for Minimizing Makespan in a flop shop with two Capacitated Batch Processing Machines. The International Journal of Advanced Manufacturing Technology, 55:1171-1182. https://doi.10.1007/s00170-010-3150-0

Nzanywayingoma, F. and Yang, Y. (2017). Analysis of Particle Swarm Optimization and Genetic Algorithm based on Task Scheduling in Cloud Computing Environment. International Journal of Advanced Computer Science and Applications, 8(1):19-25

Peres, F. and Castelli, M. (2021). Combinatorial Optimization Problems and Metaheuristics: Review, Challenges, Design and Development. https://doi:10.3390/app11146449

Phanden, R.K., Jain A., & Verma, R. (2012). A Genetic Algorithm-Based Approach for J.B. Shop Scheduling. *Journal of Manufacturing Technology Management*, 23(7): 937-940.

Pradhan, A., Bisoy, S.K. (2020). A Noval Load Balancing Technique for Cloud Computing Platform Based on PSO.

Radhika, S. and Chaparala, A. (2018). Optimization using Evolutionary Metaheuristics Techniques: A Brief Review. https://doi.org/1014488/BJOPM.2018.v15.n1.a17

Ravichandran, P., Krishnamurthy, K. and Meenakshipriya, B. (2016). A Comparison of Genetic Algorithm and Particle Swarm Optimization to Minimize the Makespan for Parallel Line Job Shop Scheduling. Research Journal of Applied Sciences, Engineering and Technology, 13(5):409-415. Doi:10.19026/rjaset.13.2959

Salido, M.A., Escamilla, J., Giret, A. and Barber, F. (2016). A Genetic Algorithm for Energy-Efficiency in Job-Shop Scheduling. The International Journal of Advanced Manufacturing. https://doi:10.1007/s00170-015-7987-0

Shao, K., Fu, H. and Wang, B. (2023). An Efficient Combination of Genetic Algorithm and Particle Swarm Optimization for Scheduling Data-Intensive Tasks in Heterogeneous Cloud Computing. Electronics, 12(3450). https://doi.org/10.3390/electronics12163450

Singh, S., Aggarwal, A. and Yadav, P.K. (2019). GA-based Task Scheduling Algorithm for Efficient Utilization of Available Resources in Computational Grid. Decision Science in Action, 119-126

Toaza, B. and Esztergar-Kiss, D. (2023). A Review of Metaheuristic algorithms for solving TSP-Based Scheduling Optimization Problems. Applied Soft Computing Journal, 148. https://doi.org/10/1016/j.asoc.2023.110908

Tran,T.A. (2018). The Optimization of Marine Diesel Engine Rotational Speed Control Process by Fuzzy Logic Control Based on Particle Swarm Optimization Algorithm. Future internet, 10(99):1-18. https://doi.org/10.3390/fi10100099

Tsetimi, J. (2010). The Use of Heuristics for Single Machine Scheduling Problem. Journal of Engineering for Development, 9:1-14.