Review on use of Swarm Intelligence Meta heuristics in Scheduling of FMS

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Abstract— Due to the high complexity of Flexible Manufacturing Systems(FMS) scheduling problem, approaches that guarantee to find the optimal solution are feasible only for small size instance of the problems with lot of computational effort and time. In contrast, approaches based on meta heuristics are capable of finding good and "near to optimal" solutions to problem instances of realistic size, in a generally smaller computation time. This work provided a review on the use of swarm intelligence meta heuristics to the scheduling of flexible manufacturing problem. The two main areas of swarm intelligence that are prominently appeared in the literature relevant to this problems are ant colony optimization (ACO) and particle swarm optimization (PSO). By reviewing the literature related to use of swarm intelligence meta heuristics to FMS scheduling problem, and commented on the basis of the review

Keywords: Swarm Inelligence, ACO, PSO, scheduling, FMS.

INTRODUCTION

Due to the high complexity of FMS scheduling problem, approaches that guarantee to find the optimal solution are feasible only for small size instance of the problems with lot of computational effort and time. In contrast, approaches based on meta-heuristics are capable of finding good and "near to optimal" solutions to problem instances of realistic size, in a generally smaller computation time. The term heuristic derives from the Greek verb heuriskein, that means ''to find''. The Greek suffix ''meta'' used in the word meta-heuristic means ''beyond, in an upper level''. Thus, meta-heuristics are algorithms that combine heuristics (that are usually very problem-specific) in a more general framework. Different people defined Meta heuristics in different ways, Blum, Roli[1] observed these definitions and outlined fundamental properties which characterize met heuristics:

—Met heuristics are strategies that "guide" the search process.
—The goal is to efficiently explore the search space in order to find near- optimal solutions.
—Techniques which constitute met heuristic algorithms range from simple local search procedures to complex learning processes.
—Met heuristic algorithms are approximate and usually non-deterministic.
—They may incorporate mechanisms to avoid getting trapped in confined areas of the search space.
—The basic concepts of met heuristics permit an abstract level description.
—Met heuristics are not problem-specific.
—Met heuristics may make use of domain-specific knowledge in the form of heuristics that are controlled by the upper level strategy.
—Todays more advanced met heuristics use search experience (embodied in some form of memory) to guide the search.

Some of the prominently appeared meta-heuristics in the literature for FMS scheduling problem are Genetic Algorithms(GA), Fuzzy logic approaches(FL), Ant Colony Optimization(ACO), Particle Swarm optimization(PSO), Tabu Search(TS) and Simulated Annealing(SA). Nanvala H[3], reviewed the most of the research papers, that contributed to scheduling of flexible manufacturing systems using Genetic algorithms. It was found that, in some contributions considered only single criterion and in some multi criterion. It is also observed that use of Genetic algorithm in integration with other meta heuristics like Tabu search, simulated annealing, neural networks to determine the optimized schedule in an FMS. Nanvala H[3], reviewed the most of the research papers, that contributed to scheduling of flexible manufacturing systems using fuzzy logic approach As fuzzy logic approaches easily deal with uncertain and incomplete information, and human experts knowledge can be easily coded into fuzzy rules, It was found that these approaches given a very good and robust performance. It is also observed that use of fuzzy logic approaches has been successfully applied in integration with other meta heuristics like genetic algorithms, evolutionary algorithms, for FMS scheduling problems. This work is focused on swarm intelligence methods for

solving scheduling of flexible manufacturing systems. The two main areas of swarm intelligence that are prominently appeared in the literature relevant to this problems are ant colony optimization (ACO) and particle swarm optimization (PSO). Ajith Abraham et al[4], stated Swarm Intelligence as an innovative distributed intelligent paradigm for solving optimization problems that originally took its inspiration from the biological examples by swarming, flocking and herding phenomena in vertebrates. The complex and often coordinated behavior of swarms fascinates not only biologists but also computer scientists. The behavior of a single ant, bee, termite and wasp often is too simple, but their collective and social behavior is of vital significance. A flock of birds sweeps across the sky. A group of ants forages for food. A school of fish swims, turns, flees together, etc[Daniel M, Martin M[5]]. Social insect colonies show complex problem solving skills arising from the actions and interactions of non sophisticated individuals. Swarm Intelligence is a field of computer science that designs and studies efficient computational methods for solving problems in a way that is inspired by the behavior of real swarms or insect colonies [Bonabeau et al.[6]]. Camazine et al.[7] stated that, Principles of self organization and local or indirect communication are important for understanding the complex collective behavior . Examples, where insights into the behavior of natural swarms has influenced the design of algorithms and systems in computer science. [Bonabeau et al.[6], Middendorf [8]].

This work is focused on review of swarm intelligence methods for solving scheduling of flexible manufacturing systems. The two main areas of swarm intelligence that are prominently appeared in the literature relevant to this problem are ant colony optimization (ACO) and particle swarm optimization (PSO). Particle Swarm Optimization (PSO) incorporates swarming behaviors observed in flocks of birds, schools of fish, or swarms of bees, and even human social behavior, from which the idea is emerged [[9],[10], [11]]. PSO is a population-based optimization tool, which could be implemented and applied easily to solve various function optimization problems, or the problems that can be transformed to function optimization problems. As an algorithm, the main strength of PSO is its fast convergence. For applying PSO successfully, one of the key issues is finding how to map the problem solution into the PSO particle, which directly affects its feasibility and performance. Ant Colony Optimization (ACO) deals with artificial systems that are inspired from the foraging behavior of real ants, which are used to solve discrete optimization problems. The main idea is the indirect communication between the ants by means of chemical pheromone trials, which enables them to find short paths between their nest and food[12]..

By reviewing the literature related to application of these Meta heuristics to FMS scheduling problem, Gist of the papers is presented and finally conclusion and comments are given.

Review of literature:

The literature available on the use of swarm intelligence Meta heuristics reviewed. The two main areas of swarm intelligence that are prominently appeared in the literature relevant to this problem are ant colony optimization (ACO) and particle swarm optimization (PSO).

Ant Colony Optimization (ACO): Kumar R et al.[13], has been attempted the scheduling problem for flexible manufacturing systems (FMSs) using the ant colony optimization (ACO) technique. The proposed solution procedure applies a graph-based representation technique with nodes and arcs representing operation and transfer from one stage of processing to the other. Individual ants move from the initial node to the final node through all nodes desired to be visited. The solution of the algorithm is a collective outcome of the solution found by all the ants. The pheromone trail is updated after all the ants have found out their respective solutions. Various features like stagnation avoidance and prevention from quick convergence have been incorporated in the proposed algorithm so that the near-optimal solution is obtained for the FMS scheduling problem, which is considered as a non-polynomial (NP)-hard problem. The algorithm stabilizes to the solution in considerably lesser computational effort. Extensive computational experiments have been carried out to study the influence of various parameters on the system performance. Wang, Wu[14] propose an AC-GA hierarchical evolutionary optimization algorithm based on Petri-net modeling and simulation. In this algorithm, the process path of jobs is optimized by an ant colony optimization(ACO) approach, and a GA is proposed to optimize the sequence of operations processed on each machine. Solimanpur M et al[15], formulated single row machine layout problem of flexible manufacturing systems, as a non-linear 0-1 programming model in which the distance between the machines is sequence dependent. An ant algorithm has been developed to solve this problem. A technique is proposed to efficiently implement the proposed algorithm. The performance of the proposed heuristic is tested over a number of problems selected from the literature. Computational results indicate that the proposed approach is more effective compared to many existing algorithms in this area. Chan F.T,S, Rahul Swarnkar[16], presents a fuzzy goal programming approach to model the machine tool selection and operation allocation problem of FMS. An ant colony optimization (ACO)-based approach is applied to optimize the model and the results of the computational experiments are reported. Lining Xing et al[17], proposed a Knowledge-based Ant Colony Optimization (KACO) for solving the Flexible Job Shop Scheduling Problem (FJSSP). Knowledge model and Ant Colony Optimization (ACO) model are two modules of KACO. The ACO model takes charge of searching through the vast solution space and identifying an optimal solution. The knowledge model learns some available knowledge from the evolution, and then applies the existing knowledge to guide the current heuristic searching. The

optimization performance of the proposed approach has been improved largely by efficaciously integrating scheduling knowledge with ACO. The experimental results suggest that the proposed algorithm is a feasible and effective approach for the Flexible Job Shop Scheduling Problem.

Mahdavi I. et al[18], considered minimizing machining cost, set-up cost and material handling cost as a multi-objective problem in flexible manufacturing systems environment . They present a 0-1 integer linear programming model for the multi objective machine tool selection and operation allocation problem and due to the large scale nature of the problem, solving the problem to obtain optimal solution in a reasonable time is infeasible, Pareto ant colony optimization (P-ACO) approach for solving the multi objective problem in reasonable time is developed. Experimental results indicate effectiveness of the proposed algorithm for solving the problem. Andrea Rossi, Gino Dini[19], proposed an ant colony optimisation-based software system for solving FMS scheduling in a job-shop environment with routing flexibility, sequence-dependent setup and transportation time. In particular, the optimisation problem for a real environment, including parallel machines and operation lag times, has been approached by means of an effective pheromone trail coding and tailored ant colony operators for improving solution quality. The method used to tune the system parameters is also described. The algorithm has been tested by using standard benchmarks and problems, properly designed for a typical FMS layout. The effectiveness of the proposed system has been verified in comparison with alternative approaches. Li-Ning Xing et al., [20], proposed an Ant Colony Optimization with Linguistically Quantified Decision Functions (ACO-LQDF) for the Flexible Job Shop Scheduling Problems (FJSSP) . The novelty of the proposed approach is the interactive and fuzzy multi-objective nature of the Ant Colony Optimization (ACO) that considers the aspiration levels set by the decision maker (DM) for the objectives. The ACO's decision function is a linguistically quantified statement about acceptable distances between achieved objective values and aspiration levels. Linguistic quantifiers are represented by means of fuzzy sets. Their computational investigation indicated that this approach can tackle multi-objective FJSSP effectively. Zhang,et al.[21] proposed a hybrid of ant colony algorithm (ACA) and particle swarm optimization (PSO) to solve the multi-objective FJSP based on the analysis of objectives and their relationship. Zhang,et al[22], also proposed a master-slave hierarchical structure hybrid algorithm that the ant colony algorithm (ACA) performs as the master level and the genetic algorithm(GA) carries out at the slave level.Noureddine L et al., [23] presented a new approach based on the combination of the ant system with tabu search algorithm for solving flexible job-shop scheduling problems. The results for the reformulated problems show that the ant systems with local search meta-heuristic can find optimal solutions for different problems that can be adapted to deal with the flexible jobshop scheduling problem(FJSP). The performances of the new approach are evaluated and compared with the results obtained from other methods. The obtained results show the effectiveness of the proposed method. Ant system algorithms and the tabu search techniques described are very effective and they alone can outperform all the alternative techniques.

Li-Ning Xing et al.[24], proposed a double layer Ant Colony Optimization (ACO) algorithm is for the Flexible Job Shop Scheduling Problem (FJSSP). In the proposed algorithm, two different ACO algorithms are applied to solve the FJSSP with a hierarchical way. The primary mission of upper layer ACO algorithm is achieving an excellent assignment of operations to machines. The leading task of lower layer ACO algorithm is obtaining the optimal sequencing of operations on each machine. Experimental results suggest that the proposed algorithm is a feasible and effective approach for the multi-objective FJSSP. Udhayakumar P, Kumanan S[25], presented an active schedules and optimal sequence of job and tool that can meet minimum makespan schedule for the flexible manufacturing system. It consists of similar work center which is capable of doing many operations. The tools are stored in a common tool magazine that shares with and serves for several work centers to reduce the cost of duplicating tools in each and every work center. This type of manufacturing system is used for a manufacturing environment in which tools are expensive. To achieve the objective, the jobs and tools are sequenced and scheduled, they proposed non-traditional optimization technique such as ant colony optimization (ACO) algorithm, to derive near-optimal solutions which adopt the Extended Giffler and Thompson algorithm for active feasible schedule generation. The proposed algorithm is used for solving number of problems taken from the literature. The results available for the various existing algorithms are compared with results obtained by the ACO algorithm. The analysis reveals that ACO algorithm provides better solution with reasonable computational time. Anoop Prakash et al.[26], proposed an Adaptive Hierarchical Ant Colony Optimization (AHACO) to resolve the traditional machine loading problem in Flexible Manufacturing Systems (FMS). Machine loading is one of the most important issues that is interlinked with the efficiency and utilization of FMS. The machine loading problem is formulated in order to minimize the system unbalance and maximize the throughput, considering the job sequencing, optional machines and technological constraints. The performance of proposed AHACO has been tested over a number of benchmark problems taken from the literature. Computational results indicate that the proposed algorithm is more effective and produces promising results as compared to the existing solution methodologies in the literature. The evaluation and comparison of system efficiency and system utilization justifies the supremacy of the algorithm. Further, results obtained from the proposed algorithm have been compared with well known random search algorithm viz. genetic algorithm, simulated annealing, artificial Immune system, simple ant colony optimization, tabu search etc. In addition, the algorithm has been tested over a randomly generated problem set of varying complexities; the results validate the robustness and scalability of the algorithm utilizing the concepts of ‘heuristic gap’ and ANOVA analysis. WANG Wan-liang et al.[27], proposed a method to resolve Flexible Job-shop Scheduling Problem Based on Improved Ant

Colony Algorithm, aiming at the limit of classical job-shop problem, combining with actual manufacture instance, a rout flexible job-shop model was given, a machine choose rule was advanced, the process of improved ant colony algorithm was given. After all ants crawled, this algorithm could adjust pheromone aiming at whether it got into part convergence, this could help algorithm to get best solution faster. In the end the simulation results show that this algorithm has good performance

Dong-Sheng Xu et al.[28], proposed An Improved Ant Colony Optimization (IACO) algorithm to the Flexible Job Shop Scheduling Problem (FJSSP). IACO algorithm provides an effective integration between Ant Colony Optimization (ACO) model and knowledge model. In the IACO algorithm, knowledge model learns some available knowledge from the optimization of ACO, and then employs the existing knowledge to guide the current heuristic searching. The performance of IACO was evaluated by many benchmark instances taken from literature. Final experimental results indicate that the proposed IACO algorithm outperforms some current approaches in the quality of schedules. Li Li et al., [29], presented an improved ant colony algorithm and an algorithm in combination with particle swarm optimization algorithm and the improved ant colony algorithm for multi-objective flexible job shop scheduling problem are employed. The algorithm proposed by them, includes two parts. The first part makes use of the fast convergence of PSO to search the particles optimum position and make it as the start position of ants. The second part makes use of the merit of positive feedback and structure of solution set proposed by their improved ACA to search the global optimum scheduling. The algorithm is validated by practical instances. The results obtained have shown the proposed approach is feasible and effective for the multi-objective flexible job shop scheduling problem. Kato et al.[30], proposed an Ant Colony optimization approach for production scheduling problem in a flexible manufacturing system. The problem is treated on two perspectives, based on the modeling and the search method. The problem modeling is characterized by a high-level problem description, using the production routes as a way to represent the states of the solution space. About the collaboration concept is applied a search method based on Max-Min Ant System algorithm. The makespan value and response time obtained by the proposed approach are compared with another approach results that uses the genetic algorithms (GA) technique for the same problem. According to the results achieved, the proposed approach is effective for the problem considered, with quality solutions in a short time processing. GambardellaL.M., Montemanni R., [31], identified some weaknesses of the original Ant Colony System(ACS) method and some improvements are introduced, leading to the Enhanced Ant Colony System (EACS). The EACS algorithm is then applied to the sequential ordering problem, an optimization problem used to model many real applications such as production planning, single vehicle routing problems with pick-up and delivery constraints and transportation problems in flexible manufacturing systems.

De-Lin Luo et al [32], proposed a Hybrid Ant Colony Optimization (HACO) considering multiple objectives, to deal with the Flexible Job-Shop Scheduling Problem (FJSSP). In the HACO, ant colony optimization is used to assign operations to machines, where a new combined heuristic is designed to balance the workloads between machines while ants tend to select the machine with less processing time for those operations. After that, SPT scheduling rule is applied to sequence the operations on each machine to shorten the makespan as well as to meet the desired delivery time window. To improve the globe search performance, a designed local search is used to search the neighborhood of an obtained optimal solution for possible better solutions by the criterions of less total workloads and their variance for all machines. Simulation results show that the proposed HACO is very efficient compared with the basic ACO and other algorithms in dealing with FJSSPs. Qi Linget al.[33], developed an adaptive ant colony algorithm to solve the model, aiming at flexible job-shop scheduling on analyzing the weakness of classical job-shop. An adaptive ant colony algorithm was advanced, in the course of searching solution route, this algorithm first choose which machine process procedure is the best, then choose process which work pieces procedure. After all ants crawl adjust pheromone arm at whether algorithm get into part convergence, this can help to get best solution faster. In the end the simulation results show that the algorithm has good performance. Li-Ning Xinng et al [34], proposed a multi-population interactive coevolutionary algorithm for the flexible job shop scheduling problems. In the proposed algorithm, both the ant colony optimization and genetic algorithm with different configurations were applied to evolve each population independently. By the interaction, competition and sharing mechanism among populations, the computing resource is utilized more efficiently, and the quality of populations is improved effectively. Their experimental results have shown that the proposed algorithm is a feasible and effective approach for the flexible job shop scheduling problem

Particle swarm optimization(PSO): Liang Gao et al.[35], proposed a general particle swarm optimization model to overcome the limitations of traditional Particle Swarm Optimization (PSO) when solving the combinatorial optimization problems, by analyzing the optimization mechanism of the traditional PSO. According to the model, a General Particle Swarm Optimization (GPSO) Algorithm is presented to solve the Flexible Job-shop Scheduling Problem (FJSP). In GPSO, crossover and mutation operations in Genetic Algorithm are respectively utilized by particles to exchange information and search randomly. Besides, Tabu Search is used for particles' local search. To control the local search and convergence to the global optimum solution, time-varying crossover probability and time-varying maximum step size of Tabu Search are introduced. The experimental results show that FJSP can be solved by GPSO effectively. The feasibility of the proposed optimization model is also demonstrated. Jerald J et al. [36] designed, different scheduling mechanisms to generate optimum scheduling; these include non-traditional approaches such as genetic algorithm (GA), simulated annealing (SA) algorithm, memetic algorithm (MA) and particle swarm algorithm (PSA) by considering multiple objectives, i.e., minimising the idle time of the machine and minimising the

total penalty cost for not meeting the deadline concurrently. The results of the different optimisation algorithms (memetic algorithm, genetic algorithm, simulated annealing, and particle swarm algorithm) are compared and conclusions are presented.Feng Gu et al.[37], constructed the particle presentation for flexible job shop scheduling according to the characteristic of flexible job shop scheduling and give the detailed process for application. Finally,they compare the genetic algorithm with particle swarm optimisation. The results have shown the effectiveness of particle swarm optimisation for flexible job shop scheduling.

Li Dan et al.[38], presented a dynamic double-population particle swarm optimization(DPSO) algorithm to solve the problem that the standard PSO algorithm is easy to fall into a locally optimized point, where the population is divided into two sub-populations varying with their own evolutionary learning strategies and the information exchange between them. The algorithm thus improves its solvability for global optimization to avoid effectively the precocious convergence. Then, an ordering algorithm based on DPSO is integrated with the heuristic assignation(HA) algorithm to form a new algorithm DPSO-HA so as to solve the flexible job-shop scheduling problem(FJSP).The new algorithm is applied to a set of benchmark problems as instances, and the simulation results show the effectiveness and feasibility of DPSO-HA algorithm for the flexible job-shop scheduling. Sandhyarani Biswas, Mahapatra S,S [39] addressed Machine Loading problem in Flexible Manufacturing System using mutation in particle swarm optimization (PSO) to avoid premature convergence with the objective of minimization of system unbalance.Ponnambalam S. G., Low Seng Kiat [40] proposed a particle swarm optimization (PSO) algorithm is proposed to solve machine loading problem in flexible manufacturing system (FMS), with bicriterion objectives of minimizing system unbalance and maximizing system throughput in the occurrence of technological constraints such as available machining time and tool slots. A mathematical model is used to select machines, assign operations and the required tools. Asokan P. et al. [41] deal with the problem of scheduling of jobs and Automated Storage and Retrieval Systems (AS/RS) assignments in a FMS environment. And implemented Non-traditional optimisation techniques such as Adaptive Genetic Algorithm (AGA) and Particle Swarm Optimisation (PSO) to get optimal schedules and storage assignments. The objective function minimises the distance travelled by the Storage and Retrieval (S/R) machine. . Girish B.S, Jawahar N.[42] proposed a particle swarm optimization (PSO) based heuristic for solving the FJSP for minimum makespan time criterion. The performance of the proposed PSO is evaluated by comparing its results with the results obtained using ILOG Solver, a constraint-programming tool. The comparison of the results proves the effectiveness of the proposed PSO for solving FJSP instances.

Jun-qing Li et al[43] proposed a hybrid algorithm with particle swarm optimization (PSO) and tabu search algorithm (TS) for solving the FJSP problems. Some novel approaches are introduced in the hybrid algorithm: a new chromosome representation for the FJSP solutions is presented; some novel crossover and mutation functions for the generation evolutionary are developed. In each generation, they used tabu search algorithm to find near optimum solutions for the obtained best solution. In the local search process, they used critical block neighborhood structure to decrease the local search space. After detailed experiments, the results show that their hybrid algorithm can obtain better solutions in very short periodGhasem Moslehi , Mehdi Mahnam [44] presented a new approach based on a hybridization of the particle swarm and local search algorithm to solve the multi-objective flexible job-shop scheduling problem.. The multi-objective particle swarm algorithm is applied to the flexible job-shop scheduling problem based on priority. Also the presented approach will be evaluated for their efficiency against the results reported for similar algorithms (weighted summation of objectives and Pareto approaches). The results indicate that the proposed algorithm satisfactorily captures the multi-objective flexible job-shop problem and competes well with similar approaches. Guohui Zhang et al. [45] combined a particle swarm optimization (PSO) algorithm and a tabu search (TS) algorithm to solve the multi-objective FJSP with several conflicting and incommensurable objectives. PSO which integrates local search and global search scheme possesses high search efficiency. And, TS is a meta-heuristic which is designed for finding a near optimal solution of combinatorial optimization problems. Through reasonably hybridizing the two optimization algorithms, an effective hybrid approach for the multi-objective FJSP has been proposed. The computational results have proved that the proposed hybrid algorithm is an efficient and effective approach to solve the multi-objective FJSP, especially for the problems on a large scale.

Zhaohong Jia et al.[46] presented an improved particle swarm optimization(PSO) algorithm to solve the multi-objective flexible job-shop scheduling problem, which integrates the global search ability of PSO and the superiority of escaping from a local optimum with chaos. Firstly, the parameters of PSO are self-adaptively adjusted to balance the exploration and the exploitation abilities efficiently. Secondly, during the search of PSO, a chaotic local optimizer is adopted to improve its resulting precision and convergence rate. Experiments with typical problem instances are conducted to compare the performance of the proposed method with some other methods. The experimental analysis indicates that the proposed method performs better than the others in terms of the quality of solutions and computational time.Zhao-hong Jia et al.[47], proposed a novel Pareto-based multi-objective Fully-informed Particle Swarm algorithm (FIPS) to solve flexible job-shop problems. Firstly, the population is ranked based on Pareto optimal concept. And the neighborhood topology used in FIPS is based on the Pareto rank. Secondly,

the crowding distance of individuals is computed in the same Pareto level for the secondary rank. Thirdly, addressing the problem of trapping into the local optimal, the mutation operators based on the coding mechanism are introduced into their algorithm. Finally, the performance of the proposed algorithm is demonstrated by applying it to several benchmark instances and comparing the experimental results.. Weijun Xia, Zhiming Wu [48] developed an easily implemented hybrid approach for the multi-objective flexible job-shop scheduling problem (FJSP) by reasonably hybridizing Simulated annealing (SA) and Particle swarm optimization(PSO). The results obtained from the computational study have shown that the proposed algorithm is a viable and effective approach for the multi-objective FJSP, especially for problems on a large scale.Liu H et al.[39],introduced a hybrid metaheuristic, the Variable Neighborhood Particle Swarm Optimization (VNPSO), consisting of a combination of the Variable Neighborhood Search (VNS) and Particle Swarm Optimization(PSO). The proposed VNPSO method is used for solving the multi-objective Flexible Job-shop Scheduling Problems (FJSP). The details of implementation for the multi-objective FJSP and the corresponding computational experiments are reported. The results indicate that the proposed algorithm is an efficient approach for the multi-objective FJSP, especially for large scale problems. Hongbo Liu et al. [50] investigated a multi-swarm PSO is for solving the multi-objective FJSP. They introduce multi swarms of particles to map different orders in the multi-objective FJSP, in which particles search for operation order update while others search for machine selection. All swarms search the optima synergistically and maintain the balance between diversity of particles and search space. Most of the research reported in the literature is focused on the single objective case of the problem, in which the objective is to find a schedule that has minimum time required to complete all operations (minimum makespan). Some other objectives, such as flow time or tardiness are also important like the makespan. Jun-qing Li, [51] given a new chromosome representation for the FJSP solutions, and proposed some novel crossover and mutation functions for the particle swarm optimization algorithm. In each generation, they used tabu search algorithm to find near optimum solutions for the given best solution. After a detailed experiment, verification of the results, they stated that their novel method can get better solutions in very short period.

Conclusion:

The use of swarm intelligence meta heuristics for scheduling of flexible manufacturing problems increased in the recent past. In the literature ACO and PSO are the prominently appeared swarm intelligence Meta heuristics for scheduling of FMS. It is also evident from the literature that, the other meta heuristics like Tabu search, Simulated Annealing, Genetic Algorithms are used in integration with ACO/SPO to determine the 'near to optimal' schedule in an FMS. It is also observed in the literature that, the effectiveness of these hybrid approaches is increased.

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