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Multi-objective scheduling in flexible manufacturing systems (FMS) using meta heuristics approach

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Abstract

Flexible manufacturing system (FMS) is a manufacturing system which enables multiple product types produced without the need of reconfiguration of the whole production line. In order to increase the efficiency of the overall FMS, manufacturing activities, as well as transport and storage tasks, need to be properly scheduled. It was observed that very few problems with multi objective scheduling has been addressed in the past years. It was observed that particle swarm optimization (PSO) gives better optimal solution as compared to genetic algorithm (GA) and tabu search (TS) for multi objective scheduling problems.

Keywords: Flexible manufacturing system, Meta heuristics, multi objective optimization, scheduling.

1. Introduction

Flexible manufacturing system (FMS) is a manufacturing system which enables multiple product types produced without the need of reconfiguration of the whole production line. Moreover, it consists a collection of numerically controlled machines with multifunction ability, an automatic material handling system and an online computer network. This network is capable of controlling and directing the whole system(Kumar et al., 2003)[28]. Its advantages of having a rapid turnaround, high quality, low inventory costs, and low labor costs, contribute to its adoption in the most recent manufacturing system in the industrial sectors (Basnet & Mize, 1994) [23].In order to increase the efficiency of the overall FMS, manufacturing activities, as well as transport and storage tasks, need to be properly scheduled. The FMS scheduling activity is affected by many features, such as the specific characteristics of the FMS, the plant in which it is located and its operational policies, the level of automation, as well as the resources belonging to the FMS (Grieco et al., 2001)[26]. The development of good quality schedules that consider all the FMS constrained resources, such as machines, AGVs, tools, buffers, is one of the main operational problems to be tackled in this kind of environment (Blazewicz et al., 1991)[24]. Especially, effective scheduling is an essential activity in manufacturing industry which leads to improvement in the efficiency and utilization of resources(Pach et al., 2014)[30].In addition, scheduling problems become extremely complex when it comes to accommodating frequent variations in the part designs of incoming jobs (Ravibabu, 2013)[33]. This research focuses on the scheduling of a variety of incoming jobs into the system efficiently and maximizing system utilization and throughput of a system where machines are equipped with different tools and tool magazines. In a context like this, the scheduling performances are expressed in terms of short-term reactivity in addition to the typical mid-term effectiveness in measuring production times, lateness, and so on. All of this makes the scheduling problem difficult to handle by the architecture which controls the FMS.

Generally, the term scheduling is an important tool for manufacturing and engineering, where it can have a major impact on the productivity of a process. In manufacturing, the purpose of scheduling is to minimize the production time and costs, by telling a production facility when to make, with which staff, and on which equipment. Production scheduling aims to maximize the efficiency of the operation and reduce costs [Magalhaes 2003]. Manufacturing model configurations (models) are presented using different software products. Models include all processes from receiving of raw materials, manufacturing to purchasing. The purchases raw materials are 'Steel-M1' and 'Gear-X' and the produces products are AX100 AX200 BX100 BX200 CX100 and CX200. They are produced through cutting, additional processing, assembly, and in the end, they are packed and sold (Simeonovova et al., 2015).

2. Utility of Various techniques in scheduling of FMS

Flexible manufacturing systems (FMSs) have emerged as a

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highly effective manufacturing strategy in the late 20th century to produce goods in medium lot sizes andmediumvariety (Veeravalli et al., 2002; Wang & Deng, 1999; Jerald et al., 2006). From a general point of view, flexibility can be understood as a characteristic of the interface between a system and its external environment. FMS scheduling comprises the following problem elements: machine loading, part routing, manufacturing tasks scheduling, tool planning and allocation, as well as the generation of the buffers usage agenda and the AGVs schedule (Novas & Henning, 2014). The majority of these papers assumed that the setup time (cost) is negligible or part of the job processing time (cost). While this assumption simplifies the analysis and/or reflects certain applications, it adversely affects the solution quality of many applications of scheduling that require an explicit treatment of setup times (costs). The interest in scheduling problems that treat setup times (costs) as separate began in the mid-1960s. The corresponding results have been summarized in the survey papers of (Allahverdi et al., 1999; Yang & Liao, 1999; Cheng et al., 2000)and (Potts & Kovalyov, 2000; Yang & Liao, 1999) concentrated on static and deterministic scheduling problems. Cheng et al. (2000) (reviewed flow shop scheduling problems, while(Potts & Kovalyov, 2000) surveyed scheduling problems with batching. Allahverdi et al. (1999)provided a comprehensive review of the literature including dynamic and stochastic problem settings in different shop environments; singlemachine, parallel machines, flow shops, and job shops. There has been a significant increase in interest in scheduling problems involving setup times (costs) since the publication of the above surveys whereby an average of more than 40 papers per year have been added to the literature. This increase stems from the fact that there are tremendous savings when setup times/costs are explicitly incorporated in scheduling decisions in various real-world industrial/service environments (Allahverdi et al., 2008).

3. Artificial Intelligence Systems

Artificial intelligence is an old dream and a fairly young discipline, which was developed since the late 1950’s as an interdisciplinary subject of computer and cognitive sciences aiming at computational models of human cognition. It is rather a marketing name for new programming methods to create reasoning systems. Computational Intelligence (CI) is the execution programming part of AI. CI relies on heuristic algorithms such as Fuzzy systems, Petrinets, Fuzzy Petrinets, Artificial Neural Networks (ANN’s), Evolutionary Computation Algorithms like GA, SA, Tabu Search, Swam particle Optimization, Artificial Immune Systems etc. CI combines elements of learning, adaptation, evolution and fuzzy logic (rough sets) to create programs that are, in some sense, intelligent. The successful use of CI in many sciences and engineering areas reveals that CI techniques are applicable to process planning and scheduling problems. AI programs can be divided into two different programs that are general and expert systems of intelligence. General systems are computer programs that attempt to simulate intelligence with no fixed limited class of problems. Consequently, programming a general system can be very difficult. Further, general systems are relatively impractical and so they are rare. In contrast, an expert system is a computer program geared towards solving one limited class of problems. Expert systems infer implications from a given knowledge base. This knowledge base may be static, pre-programmed, unchanging, and dynamic and evolution. Dynamic rule bases may be better at representing intelligence since the evolution of the rule base reflects the program’s ability to “learn”. Programs that play chess generally use static rule bases, though some chess-playing programs use dynamic rules and adapt themselves to their 4 opponent. Most artificial intelligence applications, including law applications, are formulated as rule-based expert systems. For the past three decades, there have been considerable advances in Computer Aided Engineering (CAE) tools that employ leading-edge artificial intelligence techniques and can be used with CAD/CAM tools to reduce design costs. The current AI applications, that can prove beneficial in the design and planning stages of manufacturing, can assist in solving scheduling and control problems and can be used in manufacturing integration.

4. Literature Study

The studies related to a flexible manufacturing system and various artificial intelligence techniques approached by different investigators are discussed as follows:

Erol et al. (2012) [1] proposed a multi-agent based scheduling approach for automated guided vehicles and machines within a manufacturing system. The proposed multi-agent based approach works under a real-time environment and generates feasible schedules using negotiation/bidding mechanisms between agents. This approach is tested on off-line scheduling problems from the literature. The results show that this approach is capable of generating good schedules in areal time comparable with the optimization algorithms and the frequently used dispatching rules. However, this study needs to focus towards improve the performance especially real-time scheduling of AGVs. Furthermore, they suggested investigating and additional refining the Multi-agent systems (MAS) approach to solving dynamic scheduling and controlling problems in manufacturing. Burnwal and Deb (2013)[2] implemented a cuckoo search (CS) based approach that has been developed for scheduling optimization of a flexible manufacturing system by minimizing the penalty cost due to delay in manufacturing and maximizing the machine utilization time. To demonstrate the application of cuckoo search (CS)-based scheme to find the optimum job, the proposed scheme has been applied with slight modification in its Levy flight operator because of the discrete nature of the solution on a standard FMS scheduling problem containing 43 jobs and 16 machines taken from literature. The CS scheme has been implemented using MATLAB, and results have been compared with other soft computingbased optimization approaches like genetic algorithm (GA) and particle swarm optimization found in the literature. The results shown by CS-based approach have been found to outperform the results of existing heuristic algorithms such as GA for the given problem. Novas and Henning, (2014)[3] Proposed a constraint programming approach to address the scheduling of resource-constrained flexible manufacturing systems (FMSs). The proposed CP approach has been tested by resorting to problems that consider a dissimilar number of parts, operations per part, and tool copies, as well as different AGV speeds. The various examples demonstrate the importance of having an integrated formulation and show the important errors that can occur when critical issues such as AGV empty movements are neglected. However, the obtained results have shown the impact that the tp ratio has on the solution of the integrated FMS scheduling problem. This feature can become more critical with more complex FMS lay-outs. Therefore, it also matters of future work the performance analysis of the proposed approach when varying the configuration of the FMS. Also, to assess the effect of the relative magnitude of the transport times with respect to the processing ones. Kumar (2015)[4] Suggested a generalized & modified deterministic approach towards accepting LR - type fuzzy processing time, the sequence performance measurements of makespan and job mean flow time are fuzzy in nature. Further, they have applied for GRV (Generalized Ranking Value) technique for the generalized LR - type fuzzy number. This technique, yields scheduling results with a membership function for the final completion time. The experimental results can able to help managers gain a broader overall view of scheduling. However, this study needs to concentrate towards apply other characteristics of fuzzy sets to the scheduling fields. Gang and Quan (2016)[5] described a complex structure of flexible manufacturing system and the difficulty of production planning, a general flexible manufacturing system scheduling model is built, and a List algorithm based on multi-level flexible scheduling algorithm is proposed as the core algorithm of the general model. A general planning system is developed. The model and algorithm are analyzed and verified by the plan layout, and the correctness and adaptability of the model and algorithm are proved. Khorasanian and Moslehi (2017)[6] Investigated the two-machine flow shop scheduling problem with blocking, the multi-task flexibility of the first machine, preemption, and minimization of makes pan as a criterion. In addition, two mathematical models are proposed for optimally solving the small-sized instances. Furthermore, a variable neighborhood search algorithm (VNS) and a new variant of it, namely, dynamic VNS (DVNS), are presented to find high-quality solutions for large-sized instances. The computational results show that DVNS has even a slightly better performance. The VNS and DVNS algorithms are also compared with some of the best-performing metaheuristics already developed for the flow shop scheduling problem with blocking and minimization of makes pan as a criterion. Computational results reveal that both algorithms are superior to the others for large-sized instances. In future, they suggested finding some new properties for the optimal solution for optimally solving larger instances. In addition, the DVNS algorithm could be considered as an inspiring idea to make some other metaheuristics self-adaptive. Liang Sun et al in their work [7] proposed a genetic algorithm with the penalty function for the FMS scheduling problem. For this, they used a clone selection based hyper mutation and a lifespan extended strategy. During a search process, an adaptive penalty function is decided so that the algorithm can search in both feasible and infeasible solution of the solution space. They conducted experiments on 23 benchmark and instances of the OR-Library. The proposed algorithm effectively exploits the capabilities of distributed and parallel computing of swarm intelligence approaches and effectively makes use of the famous scheme theorem and the building block hypothesis of Holland. The results indicate the successful incorporation of the proposed operators. M. Heydaret al. [8] solved the FMS scheduling problem considering two objectives i.e. maximum completion time (make span) and maximum tardiness. This scheduling problem is stated belonging to the class of NP hard problems and hence no exact method is appropriate to solve the practical cases of scheduling problems. They proposed a hybrid genetic algorithm combined with four priority dispatching rules. The proposed approach resulted in performing well in efficiency and quality of solutions. Gao, J., Sun, L., & Gen, M. (2008) [9] three objectives i.e. minimize make span, minimize maximal machine workload and minimum total workload are addressed and a hybrid genetic algorithm is proposed for a problem. They have used two vectors to represent the solution also two operators i.e. advance crossover and mutation operator are used to adapt special chromosome structure and varying characteristics of the problem. Authors have improved the genetic algorithm by variable neighborhood descent in order to strengthen the search ability. The approach used involved two local search procedure; local search of moving one operation, local search of moving two operations. They have developed an efficient method for finding assignable time intervals for the deleted operations based on the earliest and latest event times. To unify the operation sequence in chromosome with the sequence in the decoded schedule or recorded procedure is used which facilitates genetic operators to pass from the good traits of the parents. Taillard (1990) [10], [11] has shown that random pair wise swapping is computationally more expensive compared to random insertion method. Taillard has also shown experimentally that random pair wise swapping does not yield a better convergence to the optimal solution than the random insertion method. Nowicki et al. (1996) [12] propose a fast tabu search algorithm with reduced neighborhood search using a modified NEH algorithm to obtain the initial solution. The authors use block properties to explore the different sequences. By virtue of these properties, the authors were able to eliminate a considerable number of moves thereby reducing the search. The authors also employ the back jump approach in which if there is no change in the solution for a specific number of iterations, the algorithm restarts using the current best solution to create neighboring solutions. This is known as the diversification scheme in TS terminology. The authors have shown that their algorithm yields better results than Taillard (1990), Ogbu and Smith (1990), and Osman and Potts (1989) algorithms with comparable computational expense. Grabowski et al. (2004) [13] proposed a very fast tabu search algorithm for the permutation flow-shop problem to minimize the make span. The authors evaluate the solutions in the neighborhood space by computing a lower bound on the make span instead of computing the actual make span. The authors also propose a dynamic tabu list where the oldest element in the list is deleted if no favorable moves are obtained in a particular iteration and the iteration is continued. Moreover, the size of the list is also determined based on the current iteration. The authors also introduce a perturbation mechanism to diversify the search space in order to improve the performance of the neighborhood search. The perturbation mechanism is activated when there is no improvement in the solution for a fixed number of iterations. This number is chosen experimentally. The authors have found that the performance of their algorithm improved with increasing problem size when compared to Nowicki et al. [13]. They also observed that their algorithm was much faster than the existing algorithms in yielding comparable solutions. Brucker et al. [14] have proposed a tabu search algorithm for cyclic machine scheduling problems with specific application to job-shops. The authors use the disjunctive graph representation of the job-shop problem and propose a neighborhood search mechanism based on the weights of the arc which are computed in terms of the precedence of operations. The authors use the best-fit strategy for selection of a neighbor. According to this strategy, the best solution in the neighborhood of the current solution is selected for the next iteration. The authors assume unlimited buffer capacity. Parthasarathy and Rajendran (1997) [15] considered simulated annealing heuristic for scheduling to minimize total weighted tardiness in a flow shop with sequence dependent set up times. They proposed a method for obtaining the seed sequence, which is subsequently used in a simulated annealing algorithm. They presented a perturbation scheme called "random insertion perturbation scheme" when employed in the case study formed that the proposed S.A. heuristic fares much better than existing heuristic in minimizing the mean weighted tardiness of jobs. It was also observed that the best existing heuristic could not handle the real-life large sized problem. The proposed heuristic was found to result in a sequence that was superior to the sequence yielded by the existing heuristic by more than 70 %. The limitation of the study used was the awareness of the schedules of the SA technique and the implementation of complex computer code. Noorul Haq et al. (2004) [16] proposed a hybrid heuristic based on Ant System (AS) and GA approaches to minimize the make span for a flow-shop scheduling problem. The solution obtained through the AS technique is fed into the GA-based approach to further improve the solution. The authors show that the hybridization of meta-heuristic techniques yields better results when compared to pure metaheuristics techniques. Among the improvement heuristics for flow-shop scheduling, SA based and TS based algorithms have yielded good results for a wide range of scheduling problems. Low et al. (2004) [17] proposed a heuristic algorithm that combines the benefits of SA- based algorithms and TS-based algorithms. The authors use a modified NEH algorithm to generate the initial solution for the algorithm. The authors introduce a restarting mechanism into the traditional SA-based algorithm such that if there is no improvement in the solution over a specified number of iterations, a new initial solution is obtained using an auxiliary matrix which is based on the solutions explored so far and the algorithm is repeated. The authors also introduce an additional stopping criterion. The algorithm terminates when the final temperature is achieved or a specified number of iterations are executed. The authors compared their modified SA-based algorithm with other algorithms like the Ogbu and Smith algorithm (1990) for the benchmark problems proposed by Taillard (1993). They observed that although the difference in the algorithms is marginal for smaller problem sizes, their algorithm yields better results as the problem size increases. RahimiVahed and Mirghorbani [18] developed multi-objective particle swarm optimization to minimize the weighted mean completion time and weighted mean tardiness simultaneously in flow shop scheduling environment. They concluded that for large sized problems, the developed algorithm is effective as compared to genetic algorithm .Biswal [19] found superiority of hybrid genetic algorithm in which initial solutions have been searched by particle swarm optimization for multi-objective scheduling of flexible manufacturing system. Performance of the algorithm has been tested on three instances only, which has been one of the main limitations of the work. Naderi et al. [20] considered SDST hybrid flow shop scheduling to minimize make span and maximum tardiness. They hybridize the SA (HSA) with a simple local search to promote the quality of final solution. Gunashekaran et al.[52] presented a review paper on potential of FMS in research and its applications, they emphasized on the measure of flexibility and perform ability of FMS. They classified the FMS research problems into different models based on the selection of equipment, FMS layout design, material handling systems, implementation issues of FMS, part selection problem etc. R. Ram and Viswanadham [53] presented a framework for performance evaluation of manufacturing systems subject to failure and repair. They determined the mean and variance of accumulated production over a specified time frame and showed the usefulness of these results in system design and also in evaluating the operational policies for manufacturing systems. They also carried out perform ability studies on a generic model of a manufacturing system with centralized material handling. Sawik [54] proposed the multilevel approach for simultaneous machine and vehicle scheduling in a flexible manufacturing system. He highlighted the fact that, even though processing times are usually greater than transportation times in case of FMS, transportation times can also contribute to machine idle time if machines have to wait for the delivery of the next part for processing. According to him, neglecting transportation times in an FMS at the tactical planning level, as well as lack of appropriate coordination between a schedule for operations and machines and a time table for vehicle movement, can have severe consequences. Furthermore he pointed out that, when processing and transportation times are comparable, neglecting the latter at the machine loading level may lead to bottlenecks on some paths of the transportation network. Bilge and Ulsoy [55] addressed the simultaneous scheduling of machines and material handling problem in an FMS environment by time window approach. They considered identical automated guided vehicles for material transfer, which are not allowed to return to load/unload station after each delivery. They formulated the problem as a non-linear mixed integer programming model with make span minimization as the objective criterion. This formulation consists of constraint sets of machine scheduling sub problem and a vehicle scheduling sub problem which interact through a set of time window constraints for the material handling trip starting times. Ulsoy et al. [56] attempted the same problem using genetic algorithms (GA). They used a suitable coding scheme, in which chromosomes are of fixed length strings containing two consecutive locations to represent both dimensions of the search space: operation sequencing and AGV assignment. They used a special uniform crossover operator and two mutation operators.

5. Results and Discussions

In order to overcome scheduling issues, in this research planned to propose an effective multi-objective scheduling approach which is combination of the genetic Algorithm (GA), particle swarm optimization (PSO) and tabu search (TS) algorithm. The purpose of using a multi-objective genetic algorithm for effectively solving multistage-based processing schedules in FMS environment. The PSO algorithm for the scheduling optimization of FMS and TS is used for solving combinatorial optimization issues (problems where an optimal ordering and selection of options is desired). Finally, the experimental results on randomly generated instances and a real-world case demonstrate that the proposed method can achieve a better performance than other algorithms for solving the scheduling and control problem during the operation. This new approach is based on a multi-objective genetic algorithm to deal with the flexible job scheduling problems with multiple objectives. Experimental studies have been used to test the approach, and the comparisons have been made between this approach and classical GA to indicate the adaptability and superiority of the proposed approach. Finally, the corresponding computational experiments are needed to be reported. The results will indicate that the proposed algorithm is an efficient approach for the flexible job shop scheduling problems.

6. Conclusion

Following conclusion has been drawn from the present investigations.

- The particle swarm optimization (PSO) gives better optimal solution as compared to genetic algorithm (GA) and tabu search (TS) for multi objective scheduling problems.
- The experimental results on randomly generated instances and a real-world case demonstrate that the proposed method PSO and TS can achieve a better performance than other algorithms for solving the scheduling and control problem during the operation.
- This new approach is based on a multi-objective genetic algorithm to deal with the flexible job scheduling problems with multiple objectives.
- Experimental studies have been used to test the approach, and the comparisons have been made between this approach and classical GA to indicate the adaptability and superiority of the proposed approach.

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