Improving a Flexible Manufacturing Scheduling using Genetic Algorithm

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Abstract

A Flexible Manufacturing System (FMS) is designed to produce a variety of products, utilizing a set of resources like work stations, robots etc., interlinked by certain means of transport. The prime characteristic of an FMS is that the overall system is under the computer control to realize these essential improvements in a firm; it imposes many challenging problems for planning, scheduling, monitoring and control of manufacturing system. These problems have a fundamental implication on the overall performance of a FMS, and influence the responsiveness of the system to satisfy the changing customer needs. In this study, dispatching rules are used to solve the scheduling problem. Further, the multiple dispatching rule based heuristic is proposed to search the optimal sequence of operations. Genetic Algorithm (GA) is used as a random search optimization technique in the proposed heuristic. Finally, the sequence determined with the proposed heuristic is utilized to develop based intelligent controller.

Keywords: Job shop scheduling, genetic algorithm, priority rule, flexible manufacturing system, heuristics.

Introduction

In the post-industrial times, manufacturing is one of the cornerstones of our society. In the fast global changing international scenario and in the age of globalization as well liberalization, where the customers of an organization are consistently changing, and so are their requirements and demands. In such a continuously changing competitive environment coupled with varied customers’ needs, there is a need to develop a more flexible, adaptive and responsive enterprise than the existing ones like Flexible Manufacturing Systems (FMS). Usually, flexibility can be defined as the ability of surviving and prospering in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing market, driven by customer preferred products and services. The organization of business in a way, which is in adhered to these new market forces, is the hallmark of an FMS.

In current study, the solution to NP-Complete Job Shop Scheduling Problem is tried using artificial intelligence technique i.e. Genetic Algorithm. Since a Job Shop Scheduling Problem is quite difficult to solve, a lot of scope is available there to analyze the performance of each step of the algorithm used, keeping the aim as to identify different areas for improvement. Genetic algorithms solve a problem using the principal of evolution. In the search process, it will generate a new solution using genetic operator such as selection, crossover and mutation. In hill-climbing, the search procedure will stop once it detects no improvement in next iteration. This criterion make the hill-climbing technique tend to stop at local optima.

In the other hand, genetic algorithms start its search space in a population and will maintain the number of population in iteration. It will generate a new schedule by selecting two individuals in population to apply crossover and mutation. There are many procedures that could be applied in the selection, crossover and mutation process. Some of the procedures are not suitable for job-shop problem and some of them will make the search stop at local optima. This study is carried out keeping in the view to find out if the idea of combining the CB neighborhood and DG distance in crossover and mutation is suitable when dealing with job-shop scheduling problems so that the make-span value can be minimized. Result has shown that if the solution converges too quickly, it will stop at local optima. The modification has been made so that it will get a solution at least not far from optima.

The first and foremost problem of FMS is the planning problem. In order to deal with planning problem, there are various model available in literature, e.g. network model, mathematical programming model, Petri net model, etc. Similarly for scheduling problem, the techniques available in literature are mathematical programming approach, control theoretic approach, simulation approach, artificial intelligent approach and heuristic approach. It has been recognized that the scheduling optimization through mathematical programming, control theoretic and simulation approach is very difficult, because of prohibitive computation time. Due to this fact, AI techniques are used in literature. Despite, having various effective techniques, the most prevailing technique used up in real shop floor are the heuristic approaches.
In the underlying approach, the dispatching rules are used for resource allocation. From the plethora of research available in literature on dispatching rules, it is concluded that no single dispatching rule has constantly yielded better results than other in different environment. The principle motivation for undertaking this thesis has been the constant desire of the authors to study and experiment with an exhaustive set of rules and suggests a policy that will continuously deliver optimized scheduling strategy in various problem environments. Previously, Baker (1984) has suggested that it is possible to improve system performance by implementing a scheduling policy rather than a single dispatching rule. Thus, the two classes of dispatching rules that existed are static and dynamic ones. However, both the classes have several drawbacks of their own and technically optimized strategies have not achieved optimal solution so far. In order to overcome this problem, adaptive control had been applied to this problem by many researchers. Chen and Talvage (1982) and Chryssolouris et al. (1988) marked the advent of the introduction of AI into adaptive scheduling. The main idea behind using the adaptive control over dispatching rule is to utilize multiple rules as per the requirement after every operation. In order to decide the sequence of rules for each operation, few random search techniques have been utilized in this thesis.

This research is intended to conduct several experiments of the scheduling problem using the optimization techniques to schedule the dispatching rule that has been used by most of the researchers till date. To the best of the author's knowledge, Genetic Algorithm (GA), Simulated Annealing (SA) and Artificial Immune System (AIS) based techniques have not yet been used with the given problem. All the three are well known random search optimization techniques which are used here to schedule the dispatching rule for each subsequent operation. Genetic Algorithm is a powerful stochastic search technique based on natural evolution theory. In this approach, feasible solution to the problem is encoded in the form of string that resembles to chromosome. The chromosome is characterized by its fitness value, measured by its objective function value.

Simulated annealing (SA), introduced by Herdy (1991) has been widely used by operation research or management science community to solve hard combinatorial problems. It is also a random search technique that is able to escape local optima using a probability function. Unlike GA Search, SA avoids the evaluation of entire neighborhood with each iteration. A manufacturing system is said to be flexible if it is capable of processing a number of different work pieces simultaneously and automatically, with the machines on the system being able to accept and carry out the operations on the work pieces.

Talvage and Hannam (1988) defined a FMS, which has closer relationship with the system hardware and it is given as ‘A number of workstations, comprising computer-controlled machine tools and allied machines, which are capable of automatically carrying out the required manufacturing and processing operations on a number of different work pieces, with the workstation being linked by a work-handling system under the control of a computer that schedules the production and the movement of parts both between the workstations and between the workstations and system load/unload stations’.

There are two types of flexible manufacturing systems namely Random type FMS and Dedicated type FMS. Each order of a random FMS stands for one product type; the product may require several operations and may have alternative routings, i.e. several types of machine may be capable of processing the same operation, and the system may comprise of several machines of same type. A random FMS has been considered rather than a dedicated type FMS, the reason being, a dedicated type system is designed to produce a rather small family of similar parts with a known and limited variety of processing needs whereas a random FMS is designed for a large family of parts having a wide range of variations in characteristics. As a means to yield a high quality of products and to reduce lead time, companies have adhered to many FMSs for meeting crying and growing need of the production. Hence, the objective is to study the application of AIS to the scheduling problem. Finally, the author intends to do a detailed comparative study and infer conclusions from the results obtained by using these techniques.

Materials and methods
Problem description: The problem dealt with in this study is similar in characteristics to the problem taken by Shiuie and Su (2003). They had focused on an FMS project in a Belgian company. Since, FMS suppliers could meet all requirements, their project was carried out by the manufacturing company itself and they had subcontracted four machine tool builders and two suppliers of material handling systems and computer controls. In their paper, they had considered 11 different part types to be produced by the FMS and the projected weekly production of the system was 199 parts. Part weights were between 12.5 and 24 Kg and their size ranges were from $\phi$ 300*150 mm$^2$ to $\phi$ 600* 850 mm$^2$. The FMS consist of three machine families (F1, F2 and F3), three load/unload stations (L1, L2, and L3), three automatic guided vehicles (A1, A2 and A3), eleven Work In Process (WIP) buffer position, a centralized buffer, which is used for avoidance of deadlock. A local area network is used for interconnecting all the equipments. The first two machine families have two machines and the third family has only one machine.
Three robots (R1, R2 and R3) have also been included in the machine family environment and they have been deployed at the three stations to load or unload parts from the pallet, as well as from the AGVs. All the machines in the families have their own dedicated shuttle (with three or four positions). The three AGVs have one palette position and can transfer parts between stations. The layout of the FMS is diagrammatically represented in Fig. 1.

Intelligent scheduling controller: The main task of an intelligent schedule controller is to select the next part to be processed from a set of parts, Shiue and Su (2003). Work pieces can be introduced into the system using these rules and machine operations can also be scheduled. These rules may be static for a fixed scheduling period, or may be dynamic and vary over time. Before describing the dispatching rules, authors listed the notations required to define the priorities of the operations in the rules. The part to be processed is called a part. Each part consists of a set of operations, each of which can be processed on a certain set of machines (this decision is made in the planning stage). In the current study, the following priority rules are used to obtain the optimum scheduling pattern:

**Priority rules:** A priority scheduling rule is used to select the next part to be processed from a set of parts, Shiue and Su (2003). Work pieces can be introduced into the system using these rules and machine operations can also be scheduled. These rules may be static for a fixed scheduling period, or may be dynamic and vary over time. Before describing the dispatching rules, authors listed the notations required to define the priorities of the operations in the rules. The part to be processed is called a part. Each part consists of a set of operations, each of which can be processed on a certain set of machines (this decision is made in the planning stage). In the current study, the following priority rules are used to obtain the optimum scheduling pattern:

- **Shortest remaining processing time (SRPT):** According to this rule, select the part with the shortest remaining processing time. The mathematical expression for this rule is given in equation 1.
  
  \[ \text{Select } \min Z(i)(t), \text{ where } Z_i(t) = P_{ij}(t) \]  

- **Longest remaining processing time (LRPT):** According to this rule, select the part with the longest remaining processing time. The mathematical expression for this rule is given in equation 5.
  
  \[ \text{Select } \max Z(i)(t), \text{ where } Z_i(t) = R_{ij}(t) \]  

- **Longest processing time (LPT):** According to this rule, select the part with the longest processing time. The mathematical expression for this rule is given in equation 3.
  
  \[ \text{Select } \max Z(i)(t), \text{ where } Z_i(t) = TP_i \]  

- **Shortest processing time (SPT):** According to this rule, select the part with the shortest processing time. The mathematical expression for this rule is given in equation 2.
  
  \[ \text{Select } \min Z(i)(t), \text{ where } Z_i(t) = TP_i \]  

- **Longest imminent operation time (LIOT):** According to this rule, select the part with the longest imminent operation time. The mathematical expression for this rule is given in equation 4.
  
  \[ \text{Select } \max Z(i)(t), \text{ where } Z_i(t) = SIOT_{ij} \]  

- **Shortest imminent operation time (SIOT):** According to this rule, select the part with the shortest imminent operation time. The mathematical expression for this rule is given in equation 1.
  
  \[ \text{Select } \min Z(i)(t), \text{ where } Z_i(t) = LIOT_{ij} \]  

After analyzing the afore-mentioned scheduling control strategy, it can be concluded that strategies are responsible for generating a series of dispatching strategy commands to the execution function (interfaced with the physical components of FMS). Part with the utmost and highest priority is chosen for immediate processing, depending upon the availability of the machine.

**Fig. 1. Layout of flexible manufacturing system.**

![Image](image-url)
Smallest ratio (obtained by dividing the processing time of imminent operation by total processing time for the part (SDT)): According to this rule, select the part with the smallest ratio obtained by dividing the processing time of the imminent operation by the total processing time for the part. The mathematical expression for this rule is given in equation 7.

\[ \text{Select } \min Z_i(t), \text{ where } Z_i(t) = P_{i,j_0} / TP_i \]  

\[ (7) \]

Smallest value (obtained by multiplying processing time of imminent operation by total processing time for the part (SMT)): According to this rule, select the part with the smallest value obtained by multiplying the processing time of the imminent operation by the total processing time for the part. The mathematical expression for this rule is given in equation 8.

\[ \text{Select } \min Z_i(t), \text{ where } Z_i(t) = P_{i,j_0} \times TP_i \]  

\[ (8) \]

Largest ratio (obtained by dividing processing time of imminent operation by total processing time for the part (LDT)): According to this rule, select the part with the largest ratio obtained by dividing the processing time of the imminent operation by the total processing time for the part. The mathematical expression for this rule is given in equation 9.

\[ \text{Select } \max Z_i(t), \text{ where } Z_i(t) = P_{i,j_0} / TP_i \]  

\[ (9) \]

Largest value (obtained by multiplying processing time of imminent operation by total processing time for the part (LMT)): According to this rule, select the part with the largest value obtained by multiplying the processing time of the imminent operation by the total processing time for the part. The mathematical expression for this rule is given in equation 10.

\[ \text{Select } \max Z_i(t), \text{ where } Z_i(t) = P_{i,j_0} \times TP_i \]  

\[ (10) \]

The situation with a single dispatching rule becomes more critical under the presence of dynamic and uncertain environment. Therefore, it requires any dispatching strategy that may generate the sequence of the part with different set of dispatching rules and can impart flexibility in the system. Also, the varying results and related discussions in the above sections reveal that no single dispatching rule can be considered efficient and optimal during a scheduling period. In general, some rules are superior to the others only under certain specific conditions. These factors forced the researchers to identify the techniques that are highly adaptive to the system configuration and states. The application of AI based techniques in FMS scheduling are showing highly optimal results that are also adaptive in nature.

Results and discussion

Priority rule based results: The planning of the FMS is followed by scheduling the operations with appropriate resources. As discussed in earlier sections, scheduling plays a vital role in deciding the performance of any manufacturing system.

Table 1. Results obtained using priority rules.

<table>
<thead>
<tr>
<th>Priority rule</th>
<th>Mean flow time</th>
<th>Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIFO</td>
<td>1760.19</td>
<td>5242.27</td>
</tr>
<tr>
<td>MRO</td>
<td>1938.41</td>
<td>5285.42</td>
</tr>
<tr>
<td>FIFO</td>
<td>1749.32</td>
<td>5325.42</td>
</tr>
<tr>
<td>LMT</td>
<td>1825.32</td>
<td>4175.29</td>
</tr>
<tr>
<td>LDT</td>
<td>1629.12</td>
<td>5330.28</td>
</tr>
<tr>
<td>SMT</td>
<td>1150.62</td>
<td>5251.27</td>
</tr>
<tr>
<td>SDT</td>
<td>1785.24</td>
<td>5320.21</td>
</tr>
<tr>
<td>LRPT</td>
<td>1883.63</td>
<td>5245.79</td>
</tr>
<tr>
<td>SRPT</td>
<td>1161.73</td>
<td>5261.32</td>
</tr>
<tr>
<td>LIO</td>
<td>1799.36</td>
<td>4235.46</td>
</tr>
</tbody>
</table>

Thus, in order to show the effectiveness of proposed algorithm, a comparative study has been done with the several predetermined sequence of dispatching rules such as shortest processing time (SPT), longest processing time (LPT), first in first out (FIFO) etc. from the Table 1, it is evident that the solution obtained by proposed AI techniques namely GA gives significant results as compared to aforementioned predetermined part-sequencing rules.

Genetic algorithm based technique: In this study, GA has been used as a random search technique to determine an optimal sequence of dispatching rule sequence for given problem. Problem is tested using GA and the combined objective function is used which incorporates both the maximization of throughput and minimization of the mean-flow time to evaluate the fitness of a candidate solution string. Furthermore, this technique seemed to perform better than the primitive dispatching rule based scheduling measures. As the optimal sequence was generated by the GA, the problem was repeatedly run for hundreds more times to ensure the integrity and consistency of the solution and the mean of the performance measures, throughput and mean-flow time for the system is evaluated and it is used to compare the overall performance of all the scheduling techniques. The details of the parameters and results obtained using GA are given in Table 2. Therefore, it should be noted that the tuning the parameter values of GA are a complex process and affects the efficiency of the algorithm. In most of the applications of GA, these parameters are tuned on the basis of experiments. The performance of proposed algorithm has been tested over ten problems of varying complexity. Present problem consist of 11 part-type with 45 operations. The maximum number of genes in the chromosomes representing the scheduling sequence is 45 trials were conducted from population size of 10 in steps of 2 and from 20 to 50 in steps of 5. Similarly, crossover probability was varied from 0 to 0.5 in steps of 0.1 and mutation probability from 0 to 1 in steps of 0.1. The problem was also attempted by setting crossover probability to 0 and by varying mutation probability and vice versa to portray the diversity of the objective function values. The maximum generation for this problem was varied from 50 in steps of 5.
Several mutation operators were tested on the given problem. The mutation probability was varied and it was observed that unlike crossover, mutation did not result in premature convergence. However, the search space (POP_SIZ and MAX_GEN) is quite high. The results obtained reveal that RE operator outperformed others in most of the cases.

**Conclusion**

From the results obtained by the execution of all the primitive and deterministic approaches on the sample problem with varying complexities, it has been found that the performance of GA offers comparatively better results in terms of minimum mean-flow time and maximum throughput. Furthermore, the scheduling problem discussed in this study involves several variables and a multi-objective function, therefore the ability of GA to handle this type of objective functions and constraints make it a good approach to solve the problem. It also ensures the faster convergences to global optima than other random search techniques.

**References**