

# **A Systematic Review of Approaches for Flexible Job Shop Scheduling with Genetic Algorithm**

*Thesis submitted in partial fulfillment of the requirements for the award of  
degree of*

**Master of Engineering  
in  
Software Engineering**

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## Certificate

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I hereby certify that the work which is being presented in the thesis entitled, “*A Systematic Review of Approaches for Flexible Job Shop Scheduling with Genetic Algorithm*”, in partial fulfillment of the requirements for the award of degree of Master of Engineering in *Software Engineering* submitted in Computer Science and Engineering Department of Thapar Institute of Engineering and Technology, Patiala, is an authentic record of my own work carried out under the supervision of *Dr. Vinay Arora* and refers other researcher’s work which are duly listed in the reference section.

The matter presented in the thesis has not been submitted for award of any other degree of this or any other University. In case of any discrepancy (even after publication of thesis), I take the full responsibility.

  
Saryu Verma

This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge. In case of any dispute or discrepancy (even after submission of the thesis), only candidate will be responsible.



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## **Acknowledgement**

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## **Abstract**

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Scheduling is an act of describing priority of arranging activities to meet certain requirements, objectives and constraints. It is the method of assigning resources to various jobs over time to perform a collection of tasks. Scheduling can be defined as a decision making process with the aim of enhancing one or more objectives. It is concerned with the integrated ordering of operations on various machines. In the process of manufacturing, the scheduling function incorporates with other decision making functions such as materials requirements planning within the plant.

The aim of this thesis work is to provide the analysis in the domain of Flexible Job Shop Scheduling by classifying into different categories. The survey has focused on the techniques applied, methodology and tools used in these approaches. The analysis can be done on the basis of the different features and parameters used in different approaches.

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# Chapter 1

## Introduction

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Scheduling is a process of arranging activities to meet certain objectives, requirements, and constraints. It is the method that assigns resources to various jobs for performing a set of tasks. Scheduling is a process of decision making that enhances various objectives [1]. Scheduling is concerned with the integrated order of operations on a variety of machines. The scheduling function incorporates with another decision making functions in the process of manufacturing like, to plan materials requirements within the plant. Formulation, analysis, synthesis and evaluation are the most essential stages of scheduling decision [2]. Scheduling the resources of production leads to increase efficiency, profitability and utilization for the companies. At proper time and sequence, scheduling performs its work in a precedence order and delivers it to the place. Job is represented by routing, processing time. Scheduling comes after routing and the jobs can be scheduled based on different parameters like lowest processing time and most work remaining.

### 1.1 Types of Scheduling

#### 1.1.1 Job Shop Scheduling

A set of hard problems are involved by the job shop scheduling problem, which is a branch of production planning in combinatorial optimization. According to a plan, numerous operations of each job are refined in multistage system. It is basically a schedule planning for low volume systems with various variations in requirements. Finite machines handle variety of jobs that are finite in nature and are specific for static job shop scheduling. A prearranged sequence of task operations needs to be processed without preemption for a particular amount of time on a machine. A job can visit every machine one time. Tasks of the same job cannot be processed simultaneously and. If the precedent operation is still being processed and when the processing gets finished, operation will also be initiated [3]. The objective of the job shop scheduling problem is to search a schedule that minimizes the make span. A number of jobs can be processed on

various machines in job shop scheduling. A sequence of tasks ought to be performed in a specified order that is composed by a job. There should be processing of each task on a particular machine. The tasks must be scheduled on the machines in this way that the length of a schedule can be minimized. To solve the scheduling problem, a wide range of algorithms have been designed, which are based on meta-heuristics algorithms like tabu search, simulated annealing, particle swarm optimization, ant colony optimization, artificial bee colony. They also provide a swift growth in technology. It takes a long time for an output to execute the results. Thus, they are indecisive. The objectives like make span, cost, minimization of process, run time, increasing throughput and utilization of resources has selected the processing arrangement on each machine which minimized the parallel cost.

Following are some postulates given to solve job shop scheduling problem:

- There should be finite amount of jobs.
- The set of operations must be definite for each job.
- There should be fixed number of machines.
- A machine must have capability to manage one operation instantaneously.
- During a continuous period of a certain length on a machine, each operation must be processed.
- The operations are allocated to number of machines that are based on minimum time interval length, so as to find a reasonable schedule.
- Once the preceding task for a job has completed, only then the job can begin its task.
- A machine can perform only one task at a time.

### **1.1.2 Flexible Job Shop Scheduling**

The Flexible job shop scheduling problem was invented by Paolo Brandimarte in 1993. Brandimarte's original flexible job shop problem included various instances which differed according to the flexibility of the machines [4]. In the field of optimization, Flexible job shop scheduling is a NP-hard problem. It is a generalization of a classical job shop scheduling problem. On a number of available machines, the set of operations are processed. Flexible job shop scheduling is a kind of complex scheduling as it presents a

farther level of decision in contrast to the classical scheduling. In order to decide the job routes, it is essential to first determine each set of operations and then decide the processing of each machine amidst the available ones. A single machine is capable of running an operation in scheduling. An additional flexible setup is considered in flexible job shop scheduling. It is possible to run an operation on many machines when production environment is implied [5].

There are following attributes in each instance of flexible job shop scheduling:

- There are sets of jobs and machines which are defined.
- Predetermined order of operations is contained by every job.
- Operations are carried out on definite machines.
- An operation is performed one at a time and the processing time of it depends on the machine it runs.

## **1.2 Genetic Algorithm**

Genetic algorithm which is based on the theory of genetics and natural selection, are heuristic search algorithm. An intellectual utilization of a random search is represented by the algorithm, which is used to solve an optimization problem [6]. Historical information is achieved to direct the search into the area of improved performance within the search space. Simulation of the processes is essential for evolution in natural systems. For this, various techniques of Genetic algorithm are constructed. The survival of the fittest amongst individuals is simulated by genetic algorithm over consecutive generation to solve a problem [7]. A population of character strings contained by each generation is analogous to the chromosome. Each individual indicates a possible solution as well as point in a search space. In order to go through an evolution process, individuals are created in the population.

Following are some basics of genetic algorithms in which algorithm depend on an agreement with the genetic framework and character of chromosomes:

- Individuals fights for mates and resources in a population.

- An additional offspring's are generated by the individuals who are most successful in every contest than those who does not perform well.
- In order to be fit in an environment, a successive generation is developed.
- They are much more effective than a random search space.

### **1.3 Motivation**

Genetic Algorithms have the capability to provide results of higher quality with fast solutions. This makes genetic algorithm interesting to solve the optimization problems. A great number of problems are NP-Hard in computer science which takes a very long time to solve a problem. In a very short period of time, genetic algorithm has ability to provide optimal solutions [8].

### **1.4 Objectives of Genetic Algorithm**

- Genetic algorithms are used to solve scheduling problems in a very efficient way.
- Genetic algorithms are best suited for optimization and turning problems in the cases where no previous information is available.

### **1.5 Applications of GA**

- **Parameter and System Identification**

For both signal processing and control engineering, this application is proved to be an efficient mathematical model which is enviable in the systems design phase. There is a transmission of a requisite model, particularly in the structure of a transfer function. Due to the multimodal error surface of IIR together with its system stability criterion meet simultaneously. To generate an acceptable result, the gradient form of optimization algorithm has gone through a lot of difficulties [9]. To solve multimodal problem with ease, genetic algorithm has been considered as a perfect solution to the problem. The IIR filter is in the shape of cascade, lattice or parallel form. It can be chosen for optimization by using genetic algorithm.

- **Robotics**

The goal of GA is to find robot navigating system which is useful in robotics. A path can be directed for a mobile robot, which can travel in limited surroundings by using navigation system. It must be designed in a way so that the robot can cope with such kind of constraints and reach its preferred location easily without getting misled or crash into objects [10].

- **Pattern Recognition**

Pattern recognition has been widely considered in Genetic algorithm. It can be divided into two categories [11]:

- **Recognition**

A planar object which is adapted from two viewing positions can be regarded as an association. An affine transformation matrix directs a planar object. The parameters of transformation are computed by the equivalent point sets on the borders of the images.

- **Recognition of Speech**

The pre stored speech patterns has recognized the vocal patterns in an automatic system. Due to instability in time and their scales, a lot of obstacles have been faced by the communication signals. In the field of automated isolation of word identification, the reference pattern and time registration are the most crucial problems of the test.

- **Extraction**

The image filter has been designed for a two stage target identification systems, where the target picture is analyzed from the imaged data. Sub images are preferred by a linear filter in the first stage whilst for class decision; a filter bank is being developed in the last stage. In this design, encoding of real number is adapted. An appropriate way has been provided by the approach so as to design appropriate filters with a limited requirement for human intervention.

- **Planning and Scheduling**

Genetic algorithm is applied in the planning and scheduling. In order to plan the tasks, events and activity, optimization is needed. GA acts as a powerful tool to solve NP-complete problems. The applications of GA play a vital role in travelling salesman problem, job-shop scheduling and pump scheduling in water industry.

## 1.6 Phases considered in Genetic Algorithm

Various phases have been considered in genetic algorithm, which contains Initial population, Fitness function, selection, crossover and mutation.

Figure 1.1 represents the flow chart for different phases of GA for Flexible job shop scheduling. This flow chart contains initial population, fitness function, crossover, mutation and termination. The process starts with an initial population, and then parents are selected from the population for reproduction. To produce novel offspring's, crossover and mutation operators are applied on the parents. Then, these offspring's replace the existing individuals in the population and the method repeats. In this way, the human evolution has been imitated by the genetic algorithms to some point [13].

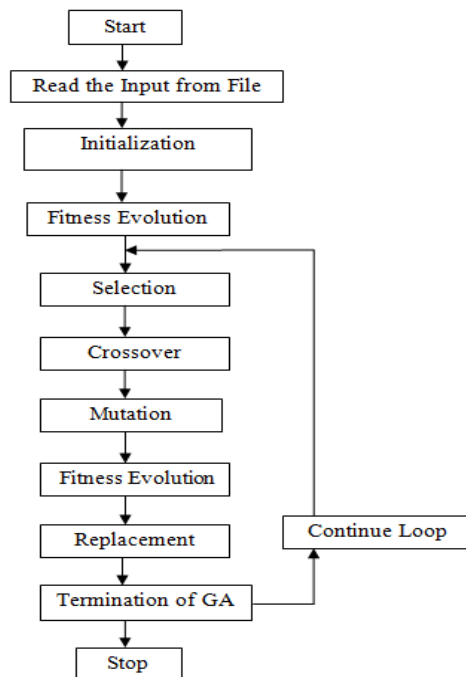


Figure 1.1. Flow Chart of Genetic Algorithm for FJSSP

### 1.6.1 Initial Population

The process starts with a set of individuals, commonly known as a Population. An individual is identified by a set of variables that can be described as genes. Genes are merged into a series to design a chromosome [14]. In a genetic algorithm, the set of genes of an individual is characterized using a string in terms of an alphabet. Generally, binary values are used (string of 1s and 0s). The genes can be encoded in a chromosome.

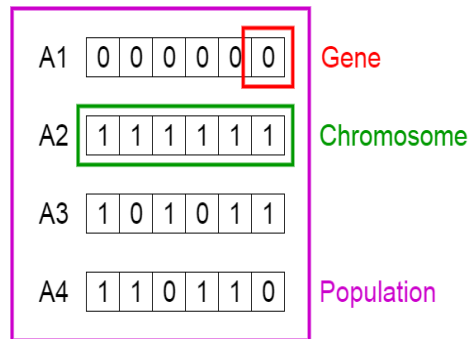


Figure 1.2 Representation of Initial populations [14]

### 1.6.2 Chromosome Representation

The chromosome representation is very essential. It is set of parameters that can be number, array of number, data structure or matrix. The chromosomes are generally represented as a binary string, although wide variety of other data structures is also used.

### 1.6.3 Fitness Function

It is the fitness function that decides how fit an individual is or how much is it capable to compete with other individuals. A fitness score is being provided to each individual. It is completely based on fitness score to choose an individual for reproduction.

### 1.6.4 Selection

It is the most essential phase of genetic algorithm, which is used to select the individuals that are fittest and then their genes are to be passed to the next generation. Based on their fitness scores, two pairs of individuals (parents) are selected. Those individuals are selected for reproduction that has high fitness value and probability [15].

### 1.6.5 Crossover Operator

Crossover is the most powerful phase in a genetic algorithm. A crossover point is selected at random within the genes in order to do mating of parents. An improved chromosome has been developed by the crossover. It modifies the outcome by swapping the information included in the current superior ones for reproduction in order to design the next generation.

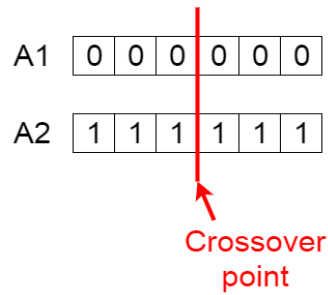


Figure 1.3 Representation of crossover [14]

Offspring are constructed by interchanging the genes of parents amidst themselves until the crossover point is attained.

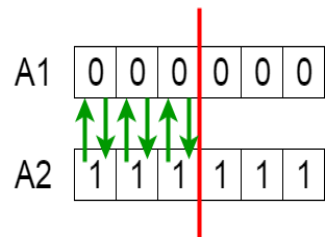


Figure 1.4 Exchanging of genes [14]

The new offspring's are added to the population.

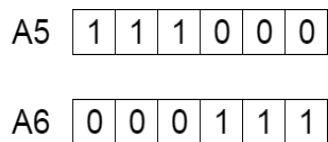


Figure 1.5 Addition of new offspring [14]

### 1.6.6 Mutation operator

When new offspring generated, some of their genes can be applied to a mutation with a low random probability. This indicates that a part of the bits in the bit string can be twisted.

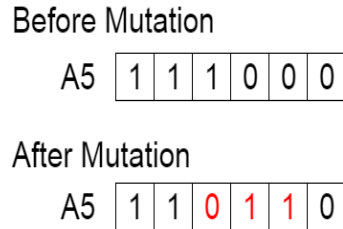


Figure 1.6 Representation of Mutation [14]

Mutation is very essential to maintain diversity and avoid premature convergence. It is used to get a new individual carrying only one value different from an already existing one.

### 1.6.7 Termination

If the population encounters or does not produce offspring that are considerably different from the past generation, then the algorithm will terminate. Thus, for a specific problem, a set of solutions are to be produced by the Genetic Algorithm.

## 1.7 Genetic Algorithm for Flexible Job Shop Scheduling

In order to get a final solution, there is no single way to solve a problem in scheduling. Researchers use various strategies, techniques to find best results. For job shop scheduling problem, heuristic algorithm is used to provide the optimal solution in an efficient way. When the inputs become more complicated and diverse then heuristic search techniques gets suffer a lot [16]. This kind of problem can also be called as a NP-Hard problem. For searching an optimal solution in polynomial time, there are no known algorithms for it. Genetic algorithm for flexible job shop scheduling, works on a population of solutions which is always ready to solve non differentiable, non continuous, multimodal or even NP-complete problems. To solve scheduling problems, genetic

algorithm is used which is a process of operational research [17]. However, current simulations and models can be integrated with genetic algorithm. To begin with an initial population, Genetic operators are applied by the algorithm to form offspring which are apparently more suitable than their ascendant. Each new chromosome is compared to a solution at every generation [8]. Many strategies can be adapted in genetic algorithm to discover individuals that can be added to the mating team in the dynamic generation and initial population phase. The power of GA corresponding to other local search algorithms is due to the fact that in a Genetic algorithm structure, at every algorithm, a variable search space is examined [18].

Here are the different research questions related to the flexible job shop scheduling. These RQs are necessary to understand the domain area, various approaches or algorithms, graphical representations and tools/ APIs used for flexible job shop scheduling.

- What is the current status of study in the field of flexible job shop scheduling?
- What are the various approaches used for flexible job shop scheduling?
- What methods, graphical illustration have been used for flexible job shop scheduling?
- Which tools are available for flexible job shop scheduling? What is the reference frequency of these tools?
- What is the future scope in the field of flexible job shop scheduling?

## Chapter 2

### Literature Survey

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In this section, various research papers are reviewed that have described different techniques and methods that have been done to understand different techniques applied on Flexible job shop scheduling. These meaningful researches added to the study to extend the existing study to a new level. There are three categorization of research paper that have been studied and considered for references are added in this chapter.

#### 2.1 Core Genetic Algorithm

A genetic algorithm is a method used for solving optimization problems that are based on natural selection and evolutionary computation. It is widely used in artificial intelligence. They are excellent for searching through large and complex data sets. Genetic algorithm has capability to find reasonable solutions to difficult problems and to solve constrained and unconstrained optimization.

**F. Pezzella *et al.* [1]** developed a genetic algorithm for the flexible job shop scheduling problem. To generate an initial population, selection of the individuals and reproduction of the new individuals, different strategies have been combined by algorithm. In order to search the initial tasks and global minimum, the approach by localization has been adopted, which has improved the assignments by reorganizing the jobs and machines. The selection criterion was selected among binary tournament and linear ranking. The GA framework was efficient in developing algorithms for scheduling problems.

**Byung Joo Park *et al.* [2]** proposed a technique based on Single and Parallel Genetic Algorithm. Initial population was accomplished through G&T algorithm and integrating representation. An approach called Island model has been designed. The remarkable performance of the GA obtained by the method of initial population, genetic operators, selection method. The temporal association has been conducted by the integration of the chromosome representation.

**Mohamed Kurdi [3]** developed a new island model for job shop scheduling problem. The objective was to minimize the make span. To improve the efficiency of the traditional island model of genetic algorithm, a migration selection mechanism and a new evolution model was proposed. This approach was able to improve the search diversification and to delay the premature convergence. In evolution model, different evolution methods were selected by island during the self-adaptation phase.

**Ehsan Ahmadi *et al.* [4]** presented an approach of refining both stability objectives and make span to deal with breakdown of machines. For the flexible job shop scheduling problem, a multi-objective methodology was proposed. NPGA and NSGA-II are the two algorithms which had been enforced on numerous cases. A set of Pareto solutions provides a range of solutions in order to make a suitable decision with the objective of stability and make span.

**P.P. Bhosale *et al.* [5]** designed a novel genetic algorithm for job shop scheduling problems. The optimal solution was discovered to solve scheduling problem. The total completion time of the entire job was minimized. Initial population was generated randomly whereas the total completion time was minimized. A schedule was found where an allocation of operation to time intervals had minimum length.

**Bilgesu Ak *et al.* [6]** proposed an improved genetic algorithm with its crossover and mutation operators, chromosome structure to guide new researchers about scheduling. With deterministic methods, it was very difficult for representation method of genetic algorithm to schedule.

**Pardeep Kumar *et al.* [7]** developed an improved genetic algorithm with new operating parameters for job shop scheduling problem in terms of make span and to obtain the optimum or a near optimum value of make span.

**Seyed Habib A. Rahmati *et al.* [8]** developed evolutionary algorithms for scheduling. The algorithms were integrated with non-dominated sorting genetic algorithm and non-

dominated ranking genetic algorithm. Pareto-based modules of new multi-objective have been used by these algorithms. When compare to NSGAI and NPGA, NSGAI gave superior results for time measure.

**Mitsuo Gen *et al.* [9]** developed a genetic algorithm integrated with a local search procedure. It used two representation methods to illustrate solution candidates for the job shop scheduling problem. For operations on the critical path, bottleneck shifting procedure has used the machines assignment and operation sequences interchanging. Local search procedure has adapted the neighborhood structure to strengthen its search ability.

**Wannaporn Teekeng *et al.* [10]** presented a modified genetic algorithm to solve flexible job shop scheduling problem. A schedule has minimized the make span of the FJSP. Chromosomes were selected by fuzzy roulette wheel selection to produce a mating pool. A hierarchical clustering model was used by a crossover to group the population in each generation. A latest mutation operator has helped in overcoming premature convergence and to maintain the population diversity.

**Fantahun M. Defersha *et al.* [11]** presented a model for a flexible job-shop scheduling. It was integrated with attached or detached setup time, sequence dependent and time lag requirements. An algorithm called parallel genetic was used to solve the model efficiently. A comprehensive solution approach had been used to understand the problem in a better way.

**Ye Li *et al.* [12]** presented an improved genetic algorithm for job shop scheduling problem. The characteristics of job shop scheduling problem were evaluated in order to reduce the make span. The chromosome structure was approved based on machine distribution and working process. The neighborhood structure was enlarged and the globally optimal solution had been accomplished.

**L. De Giovanni *et al.* [13]** developed a modified genetic algorithm to solve the problem. The objective was to minimize the global make span. The most capable individuals were modified of every generation; a local search method has been used to enhance the solutions. For non-distributed job shop scheduling, gene encoding has determined the job routings and greedy decoding procedure.

**Xinyu Li *et al.* [14]** developed a hybrid algorithm for flexible job shop scheduling. The genetic algorithm was incorporated with tabu search to reduce the make span. The exploration was performed by genetic algorithm whereas exploitation was performed by tabu search. Hybrid algorithm has balanced the intensification and diversification very well due to its high-quality of search capability. The methods containing neighborhood structure, genetic operators and encoding method has been used for scheduling.

**Nasr Al-Hinai *et al.* [15]** designed a two stage hybrid genetic algorithm to develop the analytical schedule. The main objective was optimized by the first phase. The make span was minimized in which every data was believed to be deterministic with no projected interruptions. The bi-objective functions including machines assignments and sequencing of operations has been enhanced by the second phase in the decode space. A preservation of solution quality approach was developed in order to examine both robustness and stability.

**Xiaojuan Wang *et al.* [16]** proposed a genetic algorithm to solve the multi objective flexible job shop scheduling problem. It is based on immune and entropy theory. This principle was used to maintain the diversity of individuals and to conquer the premature convergence problem. The fitness scheme has been applied which depends on the process of Pareto optimality. A novel chromosome structure was applied to avoid the loss or devastation of best solutions.

**Hao Chin Chang *et al.* [17]** proposed a method, which involved encoding the viable solutions in the genes of a genetic algorithm and to increase the effectiveness of the algorithm, the Taguchi method was enclosed after reproducing. The enhanced hybrid

Taguchi genetic algorithm was developed to overcome the limitation of the TGA. It has increased the convergence speed of genetic algorithm by avoiding unfeasible solutions.

**K. F. Man *et al.* [18]** introduced genetic algorithms as a whole entity in which knowledge of rising technology was combined to plan the structure of a design tool for industrial engineers.

**Vikas Kumar *et al.* [19]** presented a novel genetic algorithm for scheduling the problem. The performance of algorithm was enhanced by having the good use of priority scheduling. Thus, the genetic algorithm dealt with the mechanism of the conversion processing from genotype to phenotype.

**Jie Gao *et al.* [20]** proposed a genetic algorithm which has been hybridized with variable neighborhood descent in order to use the ability of global and local search. An innovative two-vector representation scheme was used to solve scheduling problem. To pass down the good quality characters of the ancestors to their offspring, genetic operators had been addressed by a reorder method to use the series in the decoded schedule. Variable neighborhood descent has enhanced the individuals of GA to strengthen its ability for search. An efficient method was used to discover flexible time intervals for those operations that have been deleted.

**Ravreet Kaur *et al.* [21]** designed a genetic algorithm with the aim of reducing the make span for job. The priorities were resolved by genetic algorithm that guide to a sub optimal result. The throughput of the system was increased by a novel genetic algorithm whereas in parallel multiprocessor system, the completion time was decreased. A suboptimal result was discovered where the tasks were allocated to the parallel multiprocessor system.

**Lihong Qiao *et al.* [22]** developed a new genetic algorithm including parallel scheduling, and constraints. An effective optimization of the model was provided by the genetic algorithm. The requirement of fast scheduling adjustment was solved by the scheduling

strategy in the production system. To deal with the complex work environment, the scheduling method has provided support to the production method.

**Yiyong He *et al.* [23]** proposed a genetic algorithm to enhance the population diversity and maintaining the convergence speed. The selection operator was improved in such a way that the same individuals were not allowed to be chosen many times. The viability relationship between selection of machines and operation sequence was maintained by the crossover operator. By reassigning the operations in the critical path, the possibility of modify the make span of a schedule had been increased by the mutation operator.

**Imran A. Chaudhry *et al.* [24]** proposed a genetic algorithm for flexible job shop problem to minimize make span. The method has implemented a domain independent GA to resolve the important aspects of the scheduling problem

**Voratas Kachitvichyanukul *et al.* [25]** proposed a genetic algorithm for job shop scheduling problem. This genetic algorithm approach has solved job shop scheduling problem which was single and multi-objective. The objective was to minimize the make span, total weighted earliness and lateness. The two-stage genetic algorithm was used to search the optimal solutions for scheduling problems. In stage 1, for each objective function, parallel GA has been applied to develop population for quality of solutions. The 2S-GA was proved to be an effective algorithm for job shop scheduling problem. However the computation time of 2S-GA was longer.

**Carsten Lehmann *et al.* [26]** proposed a novel genetic algorithm to solve the flexible job-shop scheduling problem along with make span criterion. The routing policy and the sequencing of the operations on each machine have been defined. A large class of scheduling problem was solved by genetic operators. The improved genetic algorithm has discovered high quality schedules for problems of realistic sizes.

**Deming Lei [27]** presented a fuzzy processing time for scheduling problem. An effective genetic algorithm was developed to minimize the fuzzy completion time. A decoding

method, two-string representation was used to solve a problem. In each generation, the chromosomes of the main population were decomposed to a sequence of job and separately evolved the populations of its parts.

**Nhu Binh Ho *et al.* [28]** developed architecture for flexible job shop schedules, which can be called as Learnable Genetic Architecture. LEGA has provided an effective integration between evolution and learning within a random search process. To access the quality of offspring's and diversity, the knowledge extracted from prior generation by its schema learning unit was used. The CDR Pop Gen algorithm has performed initial population generations. To decrease the workload on a machine, an operation was assigned to a appropriate machine. It has satisfied the different constraints for FJSP and has created feasible as well as active schedules.

**S. G. Ponnambalam *et al.* [29]** evaluated the four GA representation schemes to solve job-shop scheduling problems. Four representation schemes had been compared for the make span. The machine routing and the scheduling information involved a feasible and optimum sequencing of operations whilst considered technological and time-dependent constraints. A more refined schedule had been generated.

**Ameni Azzouz *et al.* [30]** examined the scheduling problem with sequence dependent setup time. The main objective was to minimize the make span. A genetic algorithm has reduced two kinds of objective functions which were make span and aggregate objectives function.

**A. Noorul Haq *et al.* [31]** proposed an algorithm to solve scheduling problem. The optimization method used was genetic algorithm. The best allocation of jobs to lines was discovered and the finest order of jobs processed in each line was depend on processing time of individuals. The optimal schedule gave the least make span for the jobs to be completed.

**Rui Zhang *et al.* [32]** presented a decomposition-based hybrid approach based on bottleneck characteristic information to solve the large scale job shop scheduling problems. In order to solve a series of sub problems, original large scale job shop problem has been handled appropriately. Moreover, the total weighted tardiness was minimized. A simulated annealing approach has defined a new sub problem, which was solved by genetic algorithm. The bottleneck attribute values of jobs were computed by fuzzy inference system. These values have represented the information of attributes in various stages of optimization. In order to promote the optimization efficiency, this information was employed to direct the procedure of sub problem.

**Athanasios C. Spanos *et al.* [33]** designed a genetic algorithm which was hybridized with crossover and mutation operators. They utilized path relining theory from tabu search and the method of combinatorial optimization. The scheme was relied on the theory of solution backbones which intensify the search in promising regions.

**Imen Driss *et al.* [34]** developed an enhanced genetic algorithm to minimize the make span. A new chromosome representation scheme and various strategies have been developed for crossover and mutation operators. This improved genetic algorithm has efficiently solved the flexible job shop scheduling problem.

**Po-Hsiang Lu<sup>1</sup> *et al.* [35]** proposed a genetic algorithm to solve the flexible job shop scheduling problem. A concise chromosome representation has been used to model a 3D scheduling of a solution by a 1-dimensional system. A 1D to 3D decoding method has converted a 1D chromosome into a 3D solution. Refinement technique has improved the performance of the scheduling. It has also changed the 3D solution to a 1D chromosome. The 3D-to-1D encoding process was intended to produce shadow chromosomes.

**Wei Sun *et al.* [36]** developed a method based on Genetic algorithm and job-shop scheduling problem with partial flexibility. Decoding algorithm, crossover and mutation operators has been improved so that search efficiency and modified GA's convergence can be enhanced. A unified mathematical model was build. This approach has solved the

complex coding problems. The genetic algorithm was able to find the best solution efficiently.

**Hamed Piroozfard *et al.* [37]** proposed the hybrid genetic algorithm to minimize the make span. To enable the structure of feasible schedules, a representation method was used. A new knowledge-based operator was used to improve the solution quality. The population diversity was increased by a neighborhood search technique and has developed local utilization ability of the algorithm.

**J. Garen [38]** proposed a genetic algorithm with a novel type of representation that allowed the utilization of recombination operators for scheduling. The new representation was tested to evaluate its effectiveness in a single-objective. Furthermore, the algorithm has been applied to two job shop scheduling problem. A set of diverse solutions, which was closed to the Pareto optimal, was found by this method.

**Smita Verma *et al.* [39]** designed a genetic algorithm for job-shop scheduling problem. It has provided a flexible structure for evolutionary computation and can tackle range of objective function and constraints. The main purpose of scheduling was to organize processes and resources. However, applications of genetic algorithm have given an efficient result. Though Genetic algorithm consumes plethora of time to provide an effective result but at the same time, it also gave a flexible framework for evolutionary computation. It was able to tackle varieties of objective functions and constraint.

**Yong Ming Wang *et al.* [40]** designed a genetic algorithm with unique chromosome encoding to handle scheduling problem. The encoding method was designed. A new genetic algorithm with particular chromosome used routing heuristics which can create superior routing and scheduling results. When a disruption occurred, the proposed approach did not integrate an operation to a machine, routing rules reassigned any operation which was affected to other machine.

**Archit Somani *et al.* [41]** presented Parallel Genetic Algorithm which was capable to modify the solutions of scheduling problem. Topological sorting has minimized the implementation time for computation of make span. The parallel topological sort has been applied by the algorithm on initial population to develop linear order.

**Qianwang Deng *et al.* [42]** presented a bee evolutionary guiding non dominated sorting genetic algorithm for FJSP. The objective was to minimize the workload or total workload of the machines and maximum time taken for completion of the tasks. In the first stage, this scheme was designed to use the solution space broadly and the NSGA-II algorithm has been used to achieve the initial population.

**Guoyong Shi *et al.* [43]** presented an encoding scheme in which a schedule had openly corresponded to an order string. A highly efficient crossover operation was elaborated in a new encoding method and the problem of infeasibility in genetic generation was conquered. Within the structure of the recently developed genetic algorithm, the NP-hard scheduling problem has been solved competently with best quality.

**Deming Lei [44]** proposed the genetic algorithm for scheduling problem. To increase the lowest agreement index and to reduce the highest fuzzy completion time, an efficient random key genetic algorithm was designed. In RKGA, a new decoding strategy and a random key representation were proposed. The performance was analyzed on random key representation and fuzzy scheduling instance.

**Vincent Lal *et al.* [45]** presented the analysis on the optimization algorithms for the flexible job shop scheduling. There were many algorithms that have been used in order to explore the optimal solution. Pareto optimality rule had enriched the solution with the ease of searching the optimal solution.

**M.B.S. Sreekara Reddy *et al.* [46]** proposed a mathematical model with objective function to reduce the total completion time and machine load variation to check the

system performance. A hybrid multi-objective evolutionary algorithm was able to discover the best solutions.

**Leila Asadzadeh *et al.* [47]** designed a parallel genetic algorithm for the scheduling problem. The creation of the initial population of genetic algorithm was accelerated by software agents. Genetic algorithm was parallelized to give the best performance. It has improved the quality of the solutions.

**Muh-Cherng Wu *et al.* [48]** proposed a genetic algorithm with new chromosome representation for job shop scheduling. The effects of using different chromosome representations were compared in order to solve a scheduling problem. The appropriate chromosome representation has been developed while genetic algorithm (or other meta-heuristic algorithm) was applied to solve a space search problem especially when the solution space was highly dimensional.

**Nilsen Kundakcı *et al.* [49]** presented a hybrid genetic algorithm where KK heuristic and dispatching rules were integrated with a genetic algorithm. They have provided quick and capable solutions for big size problems. This approach has delivered outstanding solutions for the dynamic job shop scheduling problem.

**Geoffrey Vilcot *et al.* [50]** developed a fast and elitist genetic algorithm based on NSGA-II to solve the job shop scheduling problem. The aim was the minimization of two criteria, make span, the maximum lateness and to explore an approximation of the Pareto frontier. By using a tabu search algorithm, the initial population was either generated randomly or partially that minimized a linear collaboration of the two criteria.

**James C. Chen *et al.* [51]** developed an algorithm for scheduling problem. The main aim was the minimization of various measures of performance along with total lateness and makes span. The algorithm in conjunction with Machine selection module has been selected and assigned the operations to machine whereas Operation scheduling module

has discovered the process sequence of operations on machines taking into account the priority relationships.

**Dirk C. Mattfeld *et al.* [52]** considered the significant aspects of scheduling situations and its associated performance criterion. Genetic algorithm has provided the chance to integrate priority based scheduling which as a result gave efficient optimization techniques. The Genetic algorithm has conducted a suitable search method. It has reduced the size of the search space.

**Wu Yin *et al.* [53]** proposed three Genetic algorithm methods. The processing of genetic was simplified by the punishment factor. This method was efficient as it took a less search time. Probabilistic transition was integrated with deterministic method. The algorithm has enormous application value which satisfied the rapid response requirement in scheduling.

**Lei Wang *et al.* [54]** developed a method called dynamic rescheduling which was based on the variable interval rescheduling strategy. A modified genetic algorithm was proposed for minimizing the make span. By integrating the machine with random initialization, a mixture of random initialization population has been designed to generate high quality solutions. To avoid falling into the local optimal solution, the elitist approach along with modified population diversity strategy were used.

## **2.2 Genetic Algorithm club with Meta-heuristic Algorithms**

A Genetic Algorithm with Meta-heuristic inspired by the process of natural selection that belongs to the larger class of evolutionary algorithm. It is a commonly used to generate high quality solutions to the optimization and the search problems. The aim of combining GA with Meta-heuristic algorithm is that it efficiently discovers the search space in order to find near optimal solutions.

**Osman Kulak *et al.* [55]** developed a genetic algorithm which has been integrated with dispatching rules. It has provided efficient and superior solutions for scheduling problem.

Change in processing time, new arrival of job and breakdown of machine took place in the job shop scheduling problem.

**M. Kolonko [56]** presented a novel method in which genetic algorithm was integrated with simulated annealing to produce an efficient solution. An adaptive temperature control was used to abscond local minima, crossover schedules, reheating' of SA.

**M. Gholami *et al.* [57]** investigated a meta-heuristic technique with machines to find schedules in flexible job shop scheduling. The main purpose was to reduce the make span along with mean lateness. Genetic algorithm has been integrated with simulation approach to find the best solutions and to simulate the random breakdown events. Right-shift heuristic and event driven policy were used in the simulation model to tackle the issues related to rescheduling.

**Jianchao Tang *et al.* [58]** proposed an algorithm in which the particle swarm optimization was integrated with genetic algorithm. A new initialization process was designed. The coverage of the states space was upgraded based on logistic map. According to the individuality of flexible job shop scheduling, genetic operators has been presented.

**B. S. Girish *et al.* [59]** presented a multiple job routings which belonged to the category of NP hard problems. To minimize the make span time criterion, operations were allocated to the machines by genetic and ant colony algorithm. ILOG Solver has examined the performance of these algorithms.

**L. Wang *et al.* [60]** presented a modified genetic algorithm to solve the job-shop scheduling problem. To enhance the diversity of neighborhoods and to explore potential, multiple state generators has been applied in a hybrid way. During the search process, feasible solutions were decoded into active schedules by crossover operator. To improve the neighborhood search and to avoid premature convergence, classical mutation was replaced by the simulated annealing process.

**Qiaofeng Meng *et al.* [61]** presented an efficient genetic algorithm which was integrated with tabu search and simulated annealing. The operation based representation along with crossover and mutation operation has increased individual diversity. To explore the neighborhood of the individuals, the algorithm performed local search incorporated TS and SA method. The algorithm has great advantages in both time consumption and computation.

**Guohui Zhang *et al.* [62]** developed a genetic algorithm to reduce the make span. Initial population was generated by global and local selection in the initialization phase. Every chromosome was enacted into a viable active schedule by the method of decoding. In order to enhance the quality of initial solution, a new initial assignment method was designed to produce high-quality initial population integrated with different strategies. This approach was effective to solve the flexible job shop problem. It has improved the solution's quality.

**Beatrice M. Ombuki *et al.* [63]** presented a hybrid genetic algorithm based on local search to solve the job shop scheduling problem. The Local search genetic algorithm (LSGA) employed a solution representation in which constraints such as task ordering were preserved. A genetic algorithm based scheduling scheme has been introduced which was deadlock free. Furthermore, a crossover operator assured that the solutions produced through genetic evolution were feasible. There were two advantages of LSGA. First, it was able to obtain much shorter schedule lengths. Second, it was not problem instance dependent.

**Yasuhiko Morinaga *et al.* [64]** defined optimization in medium sized enterprises where various products were manufactured in make to order form. A tabu search strategy along with genetic algorithm was applied to solve the Multi-objective FJSP.

**P. Ravichandran *et al.* [65]** described the execution of genetic algorithm and Particle Swarm Optimization to reduce the total completion time of all jobs. To increase plant

utilization, the manufacturing industry has used the parallel line job shop scheduling. It has reduced the cycle time and the allocation of jobs that were searched in many processing lines.

**Surekha P *et al.* [66]** developed a genetic algorithm to solve scheduling problem. For planning, Fuzzy logic has been applied whereas by using genetic algorithm and particle swarm optimization, scheduling could be refined.

**Q. Zhang *et al.* [67]** developed a algorithm with transportation constraints and bounded processing times. The make span and the storage of solutions were minimized. A genetic algorithm with tabu search procedure was used to resolve sequencing problems and task of resources.

### **2.3 Hybrid Genetic Algorithm with other than Meta-heuristic Algorithms**

The Genetic Algorithm can be hybridized with various approaches, other than Meta-heuristic algorithms to provide high quality solutions in Flexible Job Shop Scheduling. Heuristics are one of the most flexible techniques that make quick decisions in scheduling, especially when working with complex data. It produces a solution in a reasonable time. The Genetic Algorithm in conjunction with other than Meta-heuristic algorithms improves the efficiency of the solutions and has the ability to increase the computation time in Flexible Job Shop Scheduling. They make difficult problems simpler.

**Ren Qing-dao-er-ji *et al.* [68]** designed a genetic algorithm for job shop scheduling problem. A mixed selection operator based on the concentration and fitness value was constructed to increase the diversity of the population. A hybridized genetic algorithm was presented to calculate the critical path. The quality of the solutions has been enhanced by a local search method.

**J. G. Qi *et al.* [69]** defined the utilization of parallel genetic algorithms to meet the vibrant character of job shop scheduling. A modified genetic approach has provided an effective optimization search. With the help of different set of operations, the modified algorithm has handled jobs and various problems. It has increased the computation time and evaluations of objective function.

**Jie Gao *et al.* [70]** designed hybrid genetic algorithm with non-fixed availability constraints to solve the problem. An inventive representation method was used by genetic algorithm to signify a fraction of a resolution candidate. It has determined by the method called heuristics. The duration of chromosome and the search space has been diminished by this method. To improve the inheritability, genetic operations were applied in phenotype space. The genetic algorithm was integrated with local search to provide efficient solutions.

**Celia Gutiérrez *et al.* [71]** described a study in which genetic algorithm was combined with a method of repair heuristics. A non optimal result was provided by genetic algorithm to solve the complex problem. Afterwards, this solution was assessed and modified by heuristic approach. The flexibility of the solution to a problem has been refined by the process of repair heuristics.

**Hao-Chin Chang *et al.* [72]** proposed a genetic algorithm to solve the flexible job shop scheduling problem. The genetic algorithm was hybridized with the Taguchi approach. Illogical assignments of job were solved by new encoding method whereas complex problems were solved by genetic algorithm. Functional Mock-up Unit was encoded by the roulette method, which has selected a machine to be fused onto the initial chromosomes.

**P RA Mohana Raajan *et al.* [73]** proposed a method which was depend on the computation of evolutionary paradigms. By using genetic algorithm, scheduling was enhanced. The make span value of the optimized scheduling had been reduced. Instead of

handling a single solution, GA dealt with a population of individuals. Fuzzy interface was applied for scheduling the jobs.

**M. A. B. Candido [74]** designed a method with great number of constraints such as optional process planning for parts and sequence dependent setups. High quality solutions were generated for various problems with a set of constraints. The two meta-heuristic algorithms like tabu search and simulated annealing was implemented using the neighborhood structure. These procedures were integrated to create an efficient scheduling system.

**E. Morinaga *et al.* [75]** developed genetic algorithm for scheduling problem. Knowledge based operator included in heuristic dispatching rules was proposed by GA. Machine and job selection has been achieved sequentially in flexible job-shop production.

**José Antonio Vazquez Rodriguez *et al.* [76]** proposed dispatching rules hybridized with genetic algorithm. Each dispatching rule has handled the number of operations. The representation method was used to solve the different variants of the single objective problem as well as multi objective job shop problem with the sum of weighted tardiness objective. When tackling multi objective problems, the selection mechanism of NSGA-II was used.

**Kenichi Ida *et al.* [77]** presented approaches for survival selection, mutation, initial solution generation and escape from local optima in order to deal with FJSP. The Genetic algorithm has combined the methods that required extra search time which was caused by generation of initial solution and local optima.

**Tung Kuan Liu *et al.* [78]** presented a genetic algorithm integrated with Taguchi method to exploit the best offspring. The hybrid Taguchi genetic algorithm possessed the qualities of global searching and strength. In order to select the genes systematically and to enhance the genetic algorithm, the organized potential of the Taguchi method was included in the crossover operation.

**Abd Elrahman Elgendy *et al.* [79]** proposed a modified Genetic algorithm to enhance the utilization of resources in the dynamic environment for flexible job shop scheduling problem. The Genetic algorithm was integrated with a repair strategy to refine the make span of dynamic flexible job shop scheduling problem. The improved genetic algorithm was effective for solving the dynamic flexible job shop scheduling problem.

**Gaurav Kumar *et al.* [80]** presented a analysis of the job shop scheduling using genetic algorithm with the aim to enhanced it by minimizing the make span value and to create a mathematical model with precedence order of the jobs as constraint.

**X. Y. Li *et al.* [81]** developed a collaborative evolutionary algorithm based on Pareto optimality for multi-objective FJS. It was a capable and very efficient approach for the study of Multi objective FJSP.

**Masato Watanabe *et al.* [82]** developed a novel genetic algorithm with search area adaptation to solve scheduling problems. It has a capability to control the tradeoff stability between global and local search but also adapted to the formation of solution space despite the fact that limits of the genetic algorithm were not adjusted.

**Hsueh-Chien Cheng *et al.* [83]** presented a two-stage genetic algorithm with variety of heuristics. The proposed algorithm was a combination of the evolutionary algorithm, dispatching rules and the shifting bottleneck procedure. It has integrated a memetic algorithm and re optimization strategy of shifting bottleneck to produce a efficient solutions.

**Takeshi Yamada *et al.* [84]** proposed the application of genetic algorithm to solve a problem with the help of conventional genetic operators and a bit string representation. This method was simple and straight forward. To solve large size problems effectively, it was essential to integrate the approach with shifting bottleneck procedure or local search that used the domain specific knowledge.

## Chapter 3

### Gap Analysis

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After reviewing the literature related to Flexible Job Shop Scheduling with Genetic Algorithm, it has been figured that there exists a lacuna regarding systematic review related to Flexible Job Shop Scheduling in conjunction with Genetic Algorithm. So, the present study is focused on the following objectives:

#### Objectives:

- To analyze the concept of various heuristic and meta-heuristic algorithms based on the GA.
- To collect the relevant literature related to the Flexible Job Shop Scheduling in conjunction with Genetic Algorithm.
- Identify the various parameters for segregating the identified literature work.
- To categorize the existing algorithms under specific broader domains and compare it on the basis of identified parameters.

## Chapter 4

### Methodology

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Different methodologies, techniques, graphical representations and tools are contained by the flexible job shop scheduling, which has the ample scope of work. The systematic analysis presented, has followed the procedure of Kitchenham *et al.* [85] and it provides platform for those researchers who are working in this area. Developing the review procedure and conducting it are the segments which are included in the review development.

#### 4.1 Expansion of the review procedure

Expansion of the important areas that has to be enclosed in the review procedure and completion of the outline procedure are the two sub steps that are included by the review procedure.

##### 4.1.1 Expansion of the essential areas for the review procedure

As given in Table 1, expansion of crucial field for the review procedure incorporates the research questions with its related inspiring factor.

**Table1. Research questions**

Sr. No.	RQs	Inspiring Factor
1.	What is the current standing of study in the locale of flexible job shop scheduling?	To understand the area associated to flexible job shop scheduling.
1.1	What are the different approaches used for flexible job shop scheduling?	To identify various methods, algorithms, and graphical representations used for flexible job shop scheduling.
1.2	What methods and graphical representation have been used for flexible job shop scheduling?	To identify various methods and graphical representations used for flexible job shop scheduling.

1.3	Which tools are available for flexible job shop scheduling? What is the reference frequency of these tools?	To list the tools or the application programming interface (API) available for flexible job shop scheduling under particular approach.
1.4	What is the future scope in the area of flexible job shop scheduling?	To catalog the various sub domains under specific procedure for flexible job shop scheduling that can be explored further.

#### 4.1.2 Draft protocol finalization

Through discussion and review process, homogeneous of reported literature has accomplished the draft protocol.

### 4.2 Operating the review

To find the fundamental studies related to the research questions, systematic review has been operated. The identification of research evidence and study selection has been included by the review process.

#### 4.2.1 Identifying the research evidence

By using a optical scrutinize of the list of references from linked studies, journals, and conferences available in the form of study authors, and subject matter professionals, appropriate research publications has been chosen to identify the research evidence for organized analysis [86].

**Table 2. Search String**

Sr. No.	Source of information	Search lexis	Type of content	No.
1.	www.sciencedirect.com	Abstract: Genetic Algorithm, Flexible Job Shop Scheduling	Journals	3
		Full text: Flexible Job Shop	Journals	26

		Scheduling, Genetic Algorithm, encoding, decoding		
2.	www.link.springer.com	Flexible Job Shop Scheduling, Tabu search, local search	Journals	18
3.	www.ieeexplore.ieee.org	Abstract: Job Shop Scheduling, Genetic Algorithm Full text: Flexible Job Shop Scheduling, Genetic Algorithm, fuzzy logic, Particle swarm optimization, variable neighborhood search	Conferences  Conferences	2  9
4.	www.onlinelibrary.wiley.com	Flexible job shop scheduling, Parallel Genetic algorithm, tabu search , path relinking	Journal	1
5	Miscellaneous (from the sources including IEEE, Elsevier, Springer, Wiley)	Full text: Flexible Job Shop Scheduling, Genetic Algorithm, encoding, decoding, local search. Abstract: Flexible Job Shop Scheduling	Journals, Conferences  Journal	24  1
6	Books			3
			Total articles	87

#### 4.2.2 Selection of study

Flexible job shop scheduling with Genetic algorithm has been verified for all the researches beneath abstract. Table 2 depicts the search string for relevant research literature.

Figure 4.1. represent the study selection procedure which is divided into four steps. In analysis work, the study from different researches along with the software engineers is incorporated. Here total titles identified are 87 which are filtered on the basis of abstract and full text. Then on the basis of conferences and journals defined in full text, the chosen content of research work has been divided.

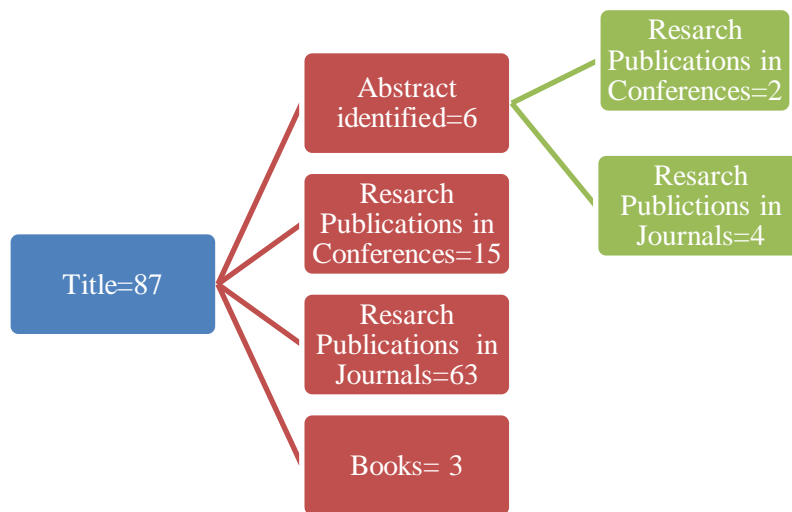


Figure 4.1 Procedure for Study selection

## Chapter 5

### Analysis and Discussion

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The aim is to survey the presented literature as per the Research questions affirmed in Table 1. The articles for research on flexible job shop scheduling are published in various Journals and Conferences Proceedings.

In Figure 5.1, the breakdown of publications has been represented, which shows the percentage wise allocation of various research publications. This distribution is deliberated for the analysis procedure. It is apparent that majority of the associated work has been published in different Journals, Conferences. The Figure shows the bifurcation of pie chart where 12.64% for Conferences, 55.17% for Journals, 28.74% for Miscellaneous and 3.45% for Books.

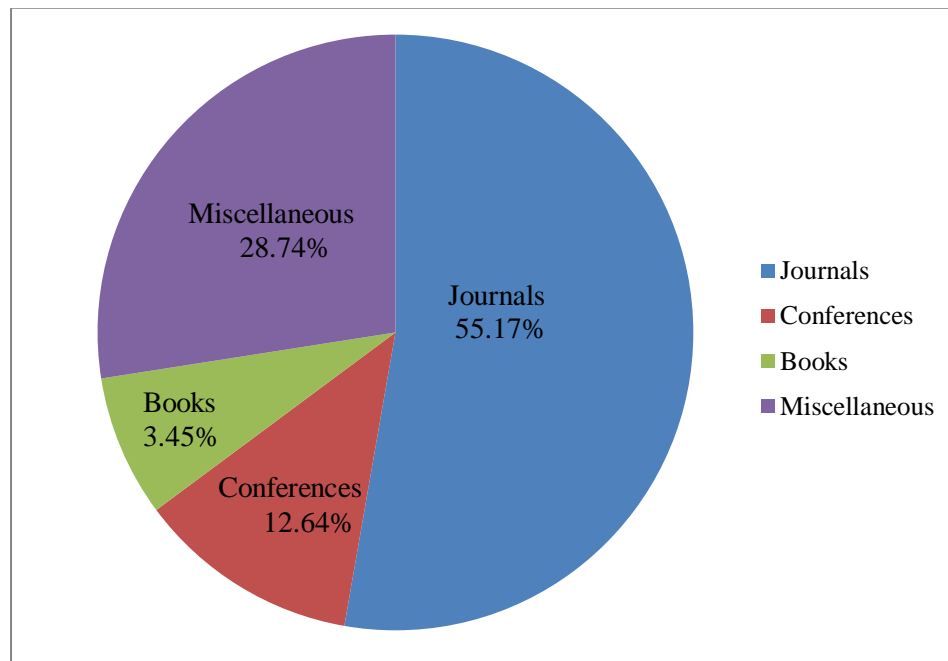


Figure 5.1 Breakdown of publications

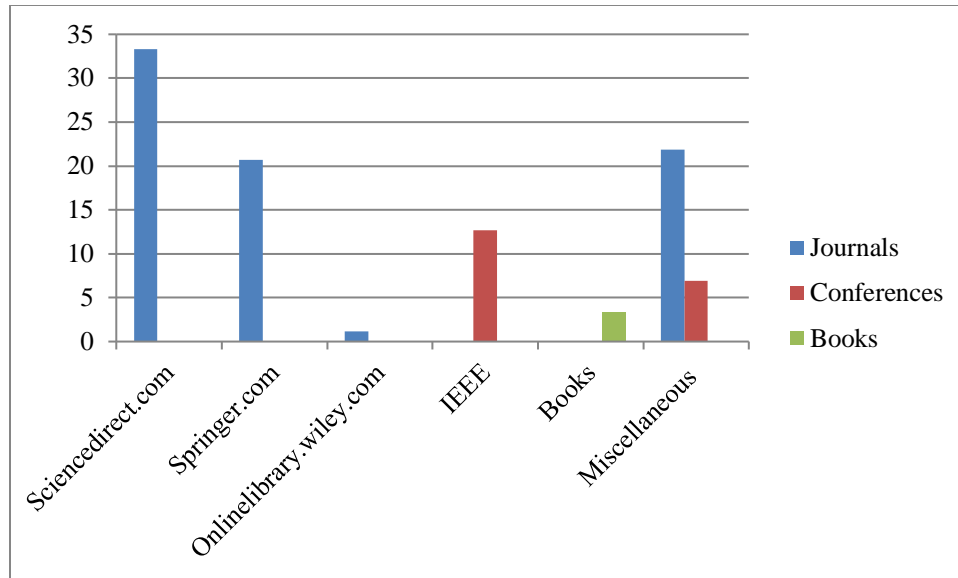


Figure 5.2 Bar graph for research publications

Figure 5.2 represents the bar graph for research publications where wide- range analysis of the literature having different point of view is presented. It is essential for the search procedure to select a germane resource of information for augmenting the possibility of discovering extremely appropriate articles. Following are the electronic sources in which broad range of search has been supported by researchers.

- Institute of Electrical and Electronics Engineers Xplore ([www.ieeexplore.ieee.org](http://www.ieeexplore.ieee.org))
- Science Direct ([www.sciencedirect.com](http://www.sciencedirect.com))
- Springer link ([www.link.springer.com](http://www.link.springer.com))
- Wiley online library ([www.onlinelibrary.com](http://www.onlinelibrary.com))
- Scientific literature Digital Library and search Engine ([www.citeseerx.ist.psu.edu](http://www.citeseerx.ist.psu.edu))
- Association for Computing Machinery Digital Library ([www.dl.acm.org](http://www.dl.acm.org))

## **5.1 Approaches for Flexible Job Shop Scheduling**

For Flexible job shop scheduling with Genetic Algorithm approaches, there is no standard categorization available. Genetic algorithm has been a widely discussed research area for scheduling problems. Based on the framework of literature survey, Research Questions, flexible job shop scheduling approaches can be broadly classified into six different schools: Core Genetic Algorithm, genetic algorithm club with Meta-heuristic algorithms, Hybrid Genetic Algorithm other than Meta-heuristic algorithms, Algorithm/technique, Tool/API and Graphical representation.

In Section 5.1.1, there is a short summary of research associated to main identified approaches in the area of flexible job shop scheduling has been discussed.

### **5.1.1 Genetic Algorithm**

Genetic algorithm is basically a local search algorithm that follows the evolution archetype. To begin with an initial population, genetic operators are applied by the algorithm to produce offspring's which are probably robust than their relations [12, 87]. Every new individual corresponds to a solution in a generation stage. Individuals are searched to add to the mating pool in the initial population stage. In a Genetic algorithm structure, more techniques can be selected jointly. A more variable search space can be discovered at every step of an algorithm [88, 89].

### **5.1.2 Meta-heuristics Algorithm**

A computational method is designed by Meta-heuristics which improves a candidate solution related to a specified quality measure [14]. For optimum solutions, Meta heuristics do not give any surety. Stochastic optimization is implemented by various Meta heuristics approaches. Meta heuristics are black box, direct search, derivative free. Here are some properties given below that describe Meta-heuristics:

- Meta-heuristics techniques are used to guide the process for searching. To search the finest solutions, the search space must be explored efficiently.
- Meta-heuristic approaches can range from easy local search to difficult process of learning.

- Algorithms in Meta-heuristics are generally non deterministic.
- They are not problem definite.

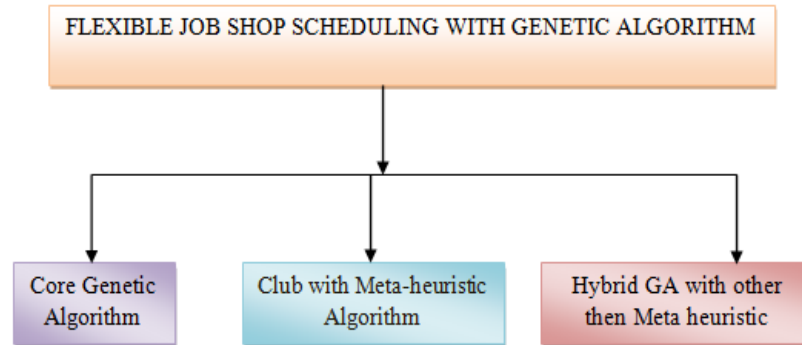


Figure 5.3 Hierarchical structures for Flexible Job Shop Scheduling with Genetic Algorithm

### 5.1.3 Hybrid Genetic Algorithm

This is a population-based search and optimization technique that imitates the procedure of natural evolution. The two major concepts of natural evolution are genetic dynamics and natural selection [21]. Genetic and other approaches can be viewed as balancing tools that can be combined together so as to attain an optimization. In these hybrids, a genetic algorithm integrates one or more methods to improve the performance of the genetic search [31]. The performance of a genetic algorithm relies upon the system for stabilizing the two contradictory objectives, which are utilizing the finest results, discover by far. The search space is explored simultaneously for efficient solutions [33]. The Genetic algorithms have capability to integrate both searching and utilization in a finest way. Though, the best use might be hypothetically accurate for a genetic algorithm but there are few troubles in carry out. It develops as the size is of population is endless and the suitability of a solution is reflected by the fitness function. The connections between genes are very limited [77, 78].

## **5.2 Genetic Algorithm club with Meta-heuristic Algorithms**

A Meta-heuristic is a higher level procedure which is designed to generate, find or select a heuristic that may provide a sufficiently good solution to an optimization problem. It may make few assumptions about the optimization problem being solved, so they may be usable for varieties of the problem. The goal of collaboration of Genetic Algorithm with Meta-heuristic is that it efficiently explore the search space in order to find near optimal solutions [16]. This section gives an overview of Genetic algorithm that has been integrated with other Meta-heuristic algorithms.

### **5.2.1 Parallel Genetic Algorithm**

The field of genetic and parallel genetic algorithms has solved the complex real world problems during recent years. Using large population sizes or to explore large search spaces with high evaluation functions, the need for quick implementation is increasing in order to allow swift and flexible experimentation [21]. Parallel processing is the essential route to discover. Moreover, standard GAs (such as premature convergence) has faced some difficulties which can be less problematic for parallel variants. Parallel Genetic algorithms can be considered as constructing new patterns among the area. Hence, it sets up an advanced field of research [33]. Demes are one alienated population (subpopulation) in several populations. On attainment the result quickly, migration has a big impact. How many migrants will be interchanged between the demes and when there is the perfect time for migration are defined by this process, Topology is an essential characteristic in a parallel computation [43]. There is much kind of topologies among nodes/demes. Genetic algorithms are effortlessly parallelized algorithms. Data parallelism and Control parallelism are two kinds of parallelism which includes the implementation of the similar process on various big data subsets simultaneously. However, control parallelism contains the synchronized implementation of several unique strategies [47].

The Figure 5.4 indicates to the classification of methods obtainable for Flexible Job Shop Scheduling with genetic algorithm. Here, core Genetic Algorithm incorporates with Meta-heuristic algorithms which is further classified into different categories including:

Parallel Genetic algorithm, Two stage Genetic Algorithm, Random key Genetic Algorithm, Non dominated ranking Genetic Algorithm, New Island model Genetic Algorithm, tabu search, firefly, variable neighborhood search, ACO, simulated annealing.

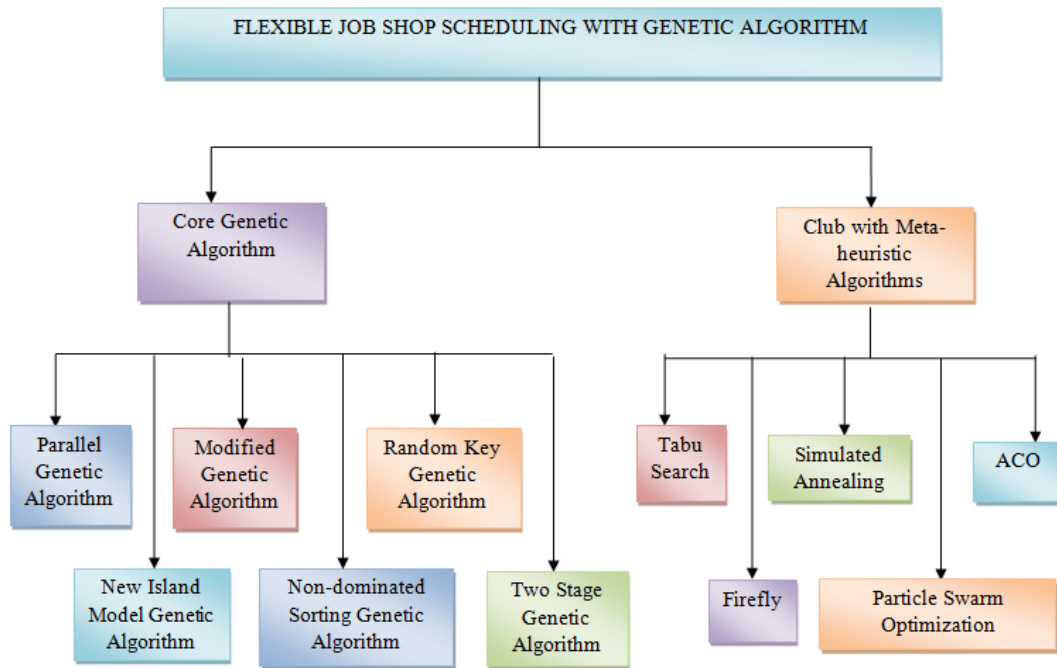


Figure 5.4. Genetic Algorithm club with Meta-heuristic algorithms

### 5.2.2 New Island Model Genetic Algorithm

A collection of sub populations that independently develop from each other in restricted areas is commonly known as Island model. Individuals in island model migrate from one area to another area. With the help of process migration, subpopulations are allowed to share genetic material. All the members are adhered together in the isolated surroundings which are more search efficient than a wider ones. Moreover, each processor can run its own genetic algorithm along with its subpopulation, which is trying to maximize the same function and one, can parallelize it by applying the process to genetic algorithm [58]. A neighborhood structure is described over the set of subpopulations and sometimes each subpopulation delivers its finest individuals to its neighbors. There can be a special case of the partitioned genetic algorithm or distributed model, if there is no swapping of individuals to neighbors is accomplished. In the case of machines, these models are most

suitable. Genetic drift will probably drive these populations into various directions because each processor begins with a different initial population. Island model has a capability to achieve differences in the subpopulations as source of genetic diversity is demonstrated by this variation. However, a large number of individuals are migrated which can drive out local differences among islands. Premature convergence of the subpopulations can occur if migration appears not often enough. The following issues must be considered to deal with an island model:

- Interchanging of the individuals by each processor.
- How often the individuals get swapped by a processor or migration frequency.
- The interchanging of individuals or Migration rate between processors.
- Exchanging of the selected individuals.
- After collecting individuals from others, the individuals must be removed.

### **5.2.3 Modified Genetic Algorithm**

Integrating the structured, randomized information with the fittest solutions based on the procedures of natural selection and genetic algorithm. Implicit parallelism is presented by the genetic algorithm that improves a set of solutions concurrently. To direct the search and to avoid the trap in a local optimum, genetic algorithm has a capability to perform on several solutions concurrently and to collect information from the present solution [13]. From the experiences of past searches, Genetic algorithm can absorb valuable redundant information through its representation of individuals in the population. To generate high quality solutions, demanding components can be captured from previous solutions which can be integrated through crossover [19]. To manage genetic algorithms convergence is not an easy task, as a pure Genetic algorithm can generate ineffective results. Due to disruptive effects of genetic operators, genetic algorithm can lose solutions [26]. A modified Genetic algorithm improves the presentation of genetic searches and prevents premature convergence. In order to control the search behavior, control temperature adjusts the mutation rate in modified genetic algorithm [79].

#### **5.2.4 Non-dominated Sorting Genetic Algorithm**

It is a well known Multi-objective evolutionary algorithm which was developed by Deb. Foundation of NSGAI is genetic algorithm. Some brand new operators and genetic algorithm operators are added to the NSGAI genetic algorithm [42]. The performance depends on the operators of any Meta heuristic algorithm. It is an expansion of the genetic algorithm for many objective function optimizations. It is analogous to other optimization algorithms like the Vector Evaluated Genetic Algorithm and Pareto Archived Evolution Strategy [46]. The two versions of the algorithm are standard NSGA and the canonical type NSGA-II. The algorithm uses a process of evolutionary for operators with backup that involves selection, crossover, and mutation [76, 77].

#### **5.2.5 Random Key Genetic Algorithm**

The algorithm is used to increase the smallest agreement index and to reduce the highest fuzzy completion time [23]. The Genetic algorithm based scheduling algorithm for flexible job shop scheduling uses the integer string to represent the result of the problem [27]. A random key scheduling algorithm is based on random key representation, a new decoding procedure, binary tournament selection. However, local search has often been integrated with the scheduling algorithms to increase the capability of optimization [44].

#### **5.2.6 Two stage Genetic Algorithm**

To develop population of superior solutions, Parallel genetic algorithm is applied by the two stage genetic algorithm for every objective function in stage 1. Then the populations that have been combined can be utilized as an initial population in Stage 2. On the fitness function, the procedure of evolution depends [15]. Through modifying the fitness function, other approaches of multi-objective can also be replaced. The job shop scheduling problem can be solved by the genetic algorithm approach. For large size problem, this method is proved to be an efficient [25].

#### **5.2.7 Meta-heuristic Techniques**

For exploiting the search space, an iterative generation method also known as meta-heuristic technique directs a subordinate heuristic by integrating unique concepts of

search space. To find optimal solutions, learning approach is used to organize the information [74]. Meta-heuristic algorithms are used to solve difficult problems. There are various Meta-heuristic algorithms which are most widely known, like Genetic algorithm, tabu search, simulated annealing and ACO [80]. They follow the evolutionary process in nature. However, in living beings memory structure is exploited by tabu search whereas in crystalline solids, the annealing process is being emulated by simulated annealing.

- **Tabu Search**

To avoid repetition of the search, tabu search keeps record of the areas of those solution spaces that have already been explored [63]. It first begins from a casual initial solution and then shifts to neighbors of the present solution. Due to exceptional short term memory of the tabu list, the method of tabu search is different from other Meta-heuristic approaches [67]. Instead of whole solution, only some of the attributes of solutions can be stored by short term memory. To revisit the solutions, no authorization is being given by it and thus, gets stuck in local optima [83].

- **Firefly Algorithm**

This algorithm was first designed by Xin-She Yang. It was based on the behavior of fireflies and flashing patterns [48]. Firefly algorithm uses these following rules:

- a) They are unisex which means that single firefly is captivated to other fireflies regardless of their gender.
- b) The magnetism is corresponding to the intensity and they both reduce whilst their distance increases. Therefore, for any two flashing fireflies, the less bright one will move towards the brighter one. If there is no brighter one than a particular firefly then it will move inconstantly.
- c) The brightness of a firefly is decided by the landscape of the objective function.

- **Genetic Algorithm**

The genetic algorithm is most widely known as Meta-heuristic algorithm. NP-hard problems can be solved by genetic algorithm. It generates an initial population randomly

and gives explanations to the difficulty called chromosomes. After a number of iterations, the population is developed by genetic algorithm. By using measure of fitness, every chromosome is assessed at each generation [18]. By either integrating two chromosomes from present generation or improving a chromosome by mutation operator, new chromosomes are produced to construct the next generation [31]. A novel generation is constructed by selection in accordance with the fitness values, a few of the parents and offspring, and declining others in order to keep the size of population fixed [90].

- **Simulated Annealing**

An ancient Meta-heuristic algorithm known as Simulated Annealing came from a similarity of how a finest atom configuration is discovered in statistical mechanics. To model the search, an explicit technique is being used by temperature [32]. By taking random tries, the solution space is analyzed in Simulated Annealing. A great number of possible solutions are developed by simulated annealing in order to keep both superior and worst solutions. During the progression of simulation, the necessities for changing an existing solution will turn into imitating the slow cooling of metallic annealing [37]. Ultimately, a small number of optimal solutions is produced by the process Simulated Annealing has capability to preclude being trapped in local minimal [60, 61].

- **Particle Swarm Optimization**

Eberhart and Kennedy have developed particle swarm optimization in 1995. A biologically inspired optimization method based on the ability and natural performance of swarms. In simple optimization problem and process static, basic PSO is appropriate [40]. For various problems, many applications has used Particle Swarm Optimization .The concept of PSO optimization came from watching some swarms moving together like ants, honeybees, fish. It adopts information of particle's previously best solution in population, so as to move the particle in the region of search space [66].

- **Ant colony optimization**

Ant colony optimization is a Meta heuristic algorithm which was proposed to handle hard combinatorial optimization problems. Exploring the behavior of real ants has been

inspiring source for ACO. Without using the visual cues, the shortest path is searched from a food source to their nest with the help of real ants. By generating a pheromone chemical substance, information is exchanged regarding the food source by ants [43]. A high amount of pheromone can be acquired as there is large traffic density of small paths. Thus, the probability of chasing the shorter paths by ants will be higher than those who have longer paths. The ACO algorithm is the version of ant colony system but the values of pheromone are limited to a bounded value [59]. The probability of designing a solution has been avoided by explicit limits on the pheromone values that fall below a certain value larger than zero. Genetic algorithm or simulated annealing has high popularity than ACO algorithms in scheduling problems [76].

### **5.3 Hybrid Genetic Algorithm with other than Meta-heuristic Algorithms**

This section gives an overview of hybridizing the Genetic algorithm with other than Meta-heuristic algorithms. Heuristics are one of the most flexible techniques that make quick decisions in scheduling, especially when working with complex data. It produces a solution in a reasonable time frame. The Genetic Algorithm in conjunction with other than Meta-heuristic algorithms improves the efficiency of the solutions. They have the capability to increase the computation time in Flexible Job Shop Scheduling. The different approaches used in scheduling such as Mixed Integer linear programming, bottleneck shifting, heuristic rules, and process routings, makes difficult problems simpler.

#### **5.3.1 Heuristics Approach**

To control machines and problem solving in human beings, Heuristics procedures has used accessible and suitable information [29]. When classic methods are ineffective to find good solutions then heuristic strategy is designed to solve a problem in the field of artificial intelligence, computer science and mathematical optimization. Hence, they can be considered as unspecific algorithms. Those solutions that are close to the best ones can be discovered quickly by these algorithms [49]. Genetic algorithm is integrated with

repair heuristics [71]. To provide a non-optimal solution, genetic algorithm can be used which does not satisfy all of its constraints. In order to enhance the solution, it applies repair heuristics approach. A solution is assessed and refined by this approach that defies a restriction in such a manner to prevent destruction [82].

The Figure 5.5 represents the various approaches for hybrid Genetic Algorithm with other than Meta-heuristic algorithms. It is further classified as heuristic rules, local search, variable neighborhood search, bottleneck shifting, variable neighborhood descent.

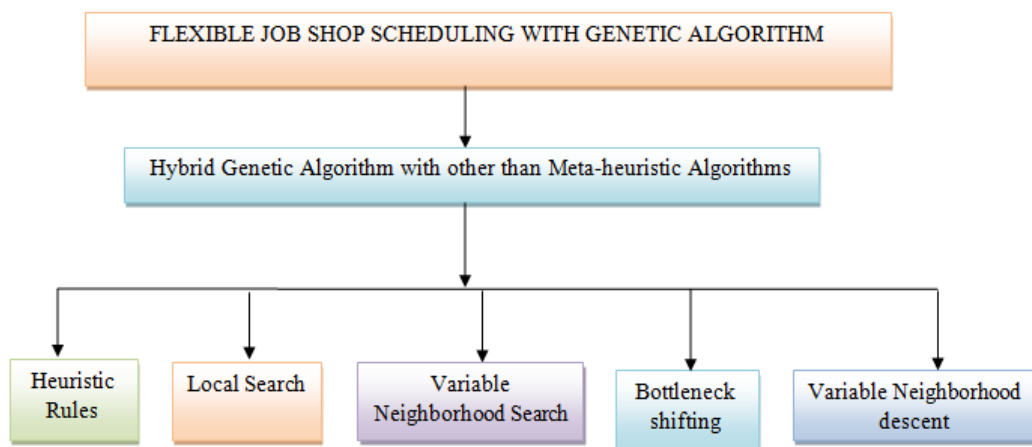


Figure 5.5 Hybrid Genetic Algorithm with other than Meta-heuristic Algorithms

### 5.3.2 Local Search

It is a form of comprehensive search which only concentrates on a definite part of the search space [13]. One of the most known hill climbing approaches comes from this class. The present solutions get displaced with the finest neighbors by these algorithms. For instance; heuristics of intra-group replication for multimedia allocation service depends on hill-climbing strategy. By making small changes, a solution is enhanced by the method of local search. In order to have a finest result, solutions can be improved over and over again [74, 75].

### **5.3.3 Variable Neighborhood Search**

A problem can be solved by a variable neighborhood search, which is one of the most novel Meta-heuristics. Due to its accomplishment in solving combinatorial optimization problems, it gathers a lot of attention on a daily basis. It is known as one of the most popular local search methods. To find the best solutions, an algorithm called local search proceeds within restricted areas of the entire search space without doing any further investigation [37]. A systematic change of neighborhood has been carried out by the variable neighborhood search procedure. Through shake and local search, the core one from the nested loop is modified and analyzed where variable neighborhood search begins with an initial solution and maneuvers it by a two-nested loop [50]. Within the local neighborhood, a modified solution is investigated by the local search; whilst by switching to other local neighborhood, the solution is expanded by the shake function. As a refresher, the inner loop is reiterated by the outer loop whereas the main search is preceded by the inner loop. As long as the solutions are refined, inner loop is repeated. When the termination condition is carried out, the outer loop reiterates and inner loop will be finished. As the freebie of neighborhood functions is the main idea behind VNS, the neighborhood search (NS) should be selected very carefully in order to achieve a highly efficient variable neighborhood search [61, 62].

### **5.3.4 Bottleneck shifting procedure**

The major certain consequence of integrating genetic algorithm with local search is the modification in the speed of convergence to local optima. In the calculation time per generation, the negative consequence is inclined [32]. When global search of genetic algorithms is not completely utilized and the presented calculation time is limited then number of generations is going to be decreased. How to allocate the calculation time wisely between genetic and local search, is the major issue of genetic algorithm [84].

### **5.3.5 Variable neighborhood descent**

This method is based on a straightforward criterion which is efficient modification of neighborhood and a randomized process of local search. In simple Genetic algorithm, the pace of evolution is slow. The convergence speed and solutions can be enhanced by the

local search. A local optimizer is connected to genetic algorithm by the combination of genetic algorithm and local search which is used on every child before it is included into the population. Genetic algorithm is generally employed to execute global searching among populations, whilst exploitation is performed all over the chromosomes by the local search [45]. It can use knowledge operator to modify the quality of solutions. The integrated strategy usually outperforms operating technique. If change of neighborhood is accomplished in a deterministic way, then this neighborhood approach will be constructed.

## **5.4 Algorithm/ Techniques available for FJSSP**

### **5.4.1 Multi-objective Evolutionary Algorithms**

To solve optimization problems, Multi-objective evolutionary algorithms are designed which is advanced generation of the Meta heuristic algorithms [16]. A group of Pareto optimal solutions has been included by this algorithm. They are capable to accurate the Pareto optimal set in a single run. From past few years, a lot of research effort has captivated by multi-objective evolutionary algorithms [22]. In the region of evolutionary computation, these algorithms are one of the most trending research areas [39]. According to selection strategy, Multi-objective Evolutionary Algorithms can be categorized in distinct ways:

- **Aggregating functions**

Objective functions are integrated into a single objective. When information is specified about decision maker with opinion then these methods can proved to be efficient.

- **Pareto-based approaches**

It is incorporated in the process of selection where the most professional algorithms are presented by this approach. A diversity of non dominated solution can be used by diverse DMs with various views. Though, there is no requirement to decision maker opinion in these algorithms [38].

- **Population-based approaches**

In order to find the area in diverse directions, population of the evolutionary algorithm is used where the search has been expanded by splitting the population into various subpopulations. In the selection process, there is no directly combination of Pareto optimality concept [81].

The Figure 5.6 represents the various Algorithm/ techniques' used for Flexible Job Shop Scheduling with Genetic Algorithm. It further classified into 8 different categories including Multi-objective Evolutionary Algorithms, A mixed integer linear programming, stochastic optimization technique, simulator algorithm, tournament selection, Roulette wheel selection.

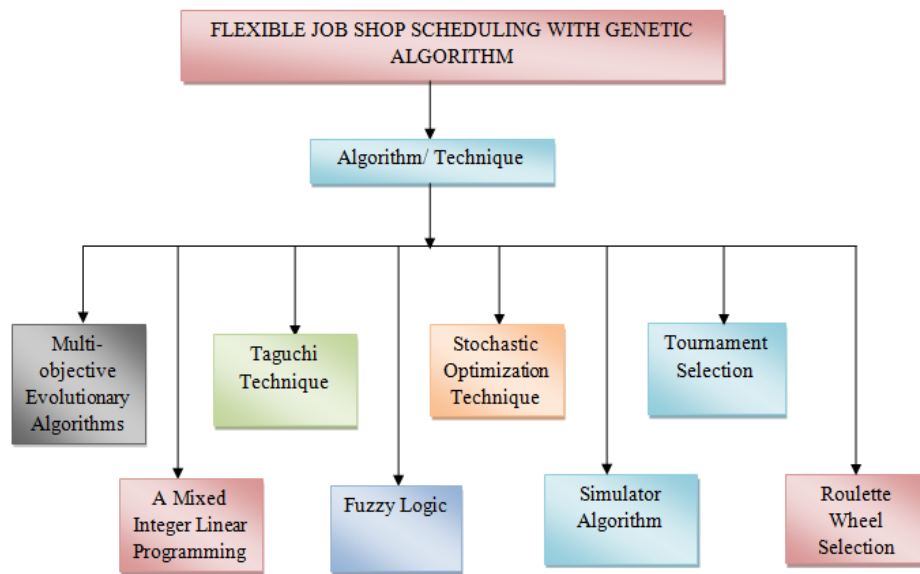


Figure 5.6 Algorithm/techniques for Flexible Job Shop Scheduling

#### 5.4.2 A Mixed Integer Linear Programming for Job Shop Scheduling

If the persistence of a job shop scheduling is developed as an integer programming then general purpose solution is modified. A collection of scheduling criteria is accommodated by integer programming approach. To enhance the solution, genetic algorithms has been applied by this approach which gives assurance of a job shop schedule as a linear

programming problem with integer adjustment. Based on a priority constraints and a set of restrictive supposition, the completion times of all jobs are minimized by the requirements [69].

#### **5.4.3 Taguchi Method**

The Job shop scheduling problems can be solved by the Hybrid Taguchi GA strategy. The genetic algorithm can be combined with the Taguchi method, which provides powerful global exploration capability and can exploit the optimal offspring [17]. The signal-to-noise ratio and the two level orthogonal array of the Taguchi method can be used for utilization [72]. Moreover, Taguchi method is a strong designing procedure that possesses the merits of robustness and has a stable solution quality. Hybrid Taguchi GA approach gives smaller standard deviations of the make span [78].

#### **5.4.4 Fuzzy Logic**

Fuzzy Logic is multi valued logic. Intermediate values among conventional assessments like true or false, high or low are described by it [60]. These values are designed mathematically and refined by computers to employ a further human like way of believing. [73]. Fuzzy Logic has been designed as a beneficial tool for controlling as well as complex industrial processes and for household and entertainment electronics. Fuzzy logic is used to execute the scheduling of jobs.

#### **5.4.5 Stochastic Optimization Technique**

Stochastic optimization is the technique of minimizing or maximizing the statistical function value when many of the input parameters are focused to randomness [24]. Stochastic means probability that is generally involved in sales, service, and business analytics (BA), finance and communications, manufacturing [40]. Stochastic processes includes probability such as trying to judge the water level in a reservoir at a fixed time based on random distribution of a water usage, rainfall and assessing the number of dropped connections in a communications network based on variable traffic but also constant available bandwidth [84].

#### **5.4.6 Simulator algorithm**

The simulator calculates the fitness values under the stochastic breakdown events when the objective function, expected mean tardiness or expected make span has been specified. In order to deal with the problem of when to reschedule, event driven policy is utilized in the simulation approach [30]. To understand about what strategies needs to apply for rescheduling, right-shift heuristic is used. Thus, to implement these subjects, the life variables and FEL variables are used.

#### **5.4.7 Tournament selection**

It is a technique of choosing an individual from a population in a genetic algorithm [27]. It includes running various tournaments amidst a chromosomes selected at random from the population. For crossover, the victor of each tournament is chosen. Selection force which is probabilistic measure of a chromosome's possibility of engaging in the tournament based on the participant selection pool size can be easily adapted by changing the tournament size. If the tournament size is bigger, weak individuals have a lesser chance to be selected because if a weak individual is selected to be in a tournament then there is a higher possibility that a stronger individual is also in that tournament [36, 37].

#### **5.4.8 Roulette Wheel Selection**

Roulette wheel is undoubtedly simplest and classical stochastic selection approach developed by Holland. It is classified beneath proportionate selection as it prefers the individuals completely based on a probability proportional to the fitness. Roulette wheel selection has used exploitation procedure in its approach. It is a process through which slots in the roulette wheel weighted in amount to the individual's fitness values. In compliance to their fitness value, all the chromosomes that are presented in the population are located on the roulette wheel. A segment of roulette wheel has been selected by each individual. In the roulette wheel, the numerical value of the fitness of the individual is proportional to the size of each segment; if the value is greater, then the segment will also be longer [20, 21]. There will be a rotation of the virtual roulette wheel. Then, those individuals are preferred that are similar to the section where roulette wheel ends. When the desired number of individuals is selected, the process gets replicated.

Those individuals, who have high fitness values, have more chances of selection [80]. The best individuals of a population can likely to be missed. Good individuals don't have any surety that they will search way towards the next generation [54].

The tabular representation gives an outlook which is independent of any programmed language. Here, Table 3 represents the different algorithm/techniques used for the flexible job shop scheduling. Along with each approach, their reference articles, count and citations have been mentioned.

**Table 3 Algorithms/ techniques for FJSSP**

S.No.	Flexible Job Shop Scheduling method	Algorithm(s)/technique(s) available	Count	Citations
1.	Core Genetic Algorithm	Parallel Genetic algorithm	6	[47, 21, 11, 2, 3, 41]
		New Island Model Genetic Algorithm	2	[2,3]
		Replacement method	1	[3]
		Migration policy	1	[3]
		G&T algorithm	2	[2, 39]
		Modified genetic algorithm	1	[10]
		Fuzzy roulette wheel selection	2	[21, 10]
		Hierarchical clustering algorithm	1	[10]
		Topological sort	1	[41]
		Path relinking	1	[33]
		Immune and Entropy principle	2	[16, 45]
		Non-dominated sorting Genetic Algorithm	4	[4, 46, 8, 50]
		Non-dominated ranking Genetic Algorithm	2	[4, 8]
		Two stage Genetic Algorithm	1	[25]
		Lamarckian evolution	1	[18]
Encoding	18	[13, 14, 17, 37, 32, 42, 52, 23, 30, 11,		

		Random key based GA	2	16, 40, 25, 35, 6, 49, 34, 19]
		Decoding	16	[44, 51]
		Artificial Immune Algorithm	1	[37, 14, 13, 9, 32, 20, 52, 12, 23, 36, 16, 25, 34, 35, 42]
		Artificial Immune Algorithm	1	[45]
2.	Hybrid GA club with Meta-heuristic Algorithm	Variable Neighborhood Search	3	[20, 13, 56]
		Neighborhood structure	5	[9, 50, 17, 62, 55]
		Tabu Search	5	[61, 63, 67, 14, 55]
		Simulation Algorithm	2	[4, 57]
		Simulated Annealing	5	[7, 61, 32, 36, 37]
		Global Search	2	[14, 61]
		Chaos Particle Swarm	3	[60, 58, 66]
		Optimization		
		Ant Colony Optimization	1	[59]
		Bee Evolutionary guided -	1	[42]
		NSGA-II		
		Artificial Bee colony Algorithm	1	[45]
		Local Search	10	[17, 14, 45, 20, 9, 67, 50, 63, 60, 61]
3.	Hybrid GA with other than Meta-heuristic algorithms	Bottleneck shifting	4	[9, 83, 84, 32]
		Heuristics rules	4	[71, 75, 76, 51]
		Hierarchical clustering algorithm	1	[10]
		Taguchi method	3	[17, 78, 72]
		Local hill climbing procedure	1	[74]
		Escape method	1	[77]
		Rescheduling strategy	1	[79]
		Dispatching rules	2	[76, 69]
		Integer linear programming	1	[69]
		Pareto optimality	2	[16, 81]
		Search area adaptation	1	[82]

		Sequence dependent setup times	2	[11, 30]
		Fuzzy processing time	1	[44]

### 5.5 Tools/ API's available for flexible job shop scheduling

API's describes generic connectivity interface to an application. Now days, API has taken on some characteristics that make them extraordinary valuable and useful. The API's follow the standard that is developer- friendly, understood broadly and easy to access.

The Figure 5.8 represents various modern tools/API that have been used for flexible job shop scheduling.

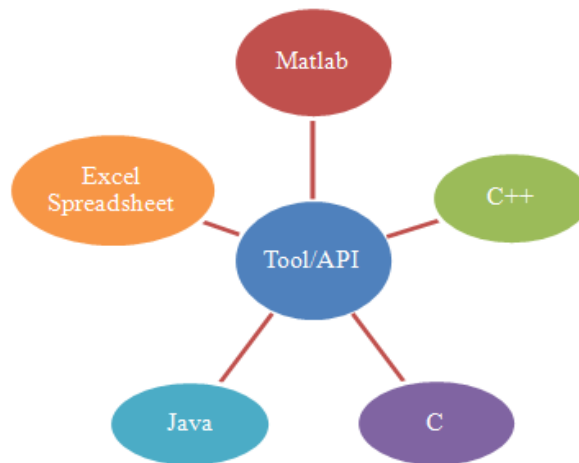


Figure 5.8 Tools/API's used for FJSSP

The Table 4 indicates the different tools/ API's (C, C++, Matlab, Java, Excel spreadsheet) used for Flexible Job Shop Scheduling with their citations. Several research papers have been studied for the Tools/API's.

**Table 4. Tools/API's used for FJSSP**

S. No.	GA approach	Tool/API	Count	Citation
1	Core Genetic Algorithm	C++	16	[3,48, 82, 28, 15, 27, 29, 77, 44, 11, 16, 40, 35, 18, 34, 81]
		C	3	[43, 31, 49]
		Matlab	8	[46, 4, 5, 7, 53, 26, 36, 8]
		Java	1	[30]
		Excel Spreadsheet	1	[24]
		Delphi	1	[9]
2	Hybrid GA club with Meta-heuristic Algorithms	C++	7	[14, 66, 37, 64, 62, 57, 60]
		C	2	[63, 59]
		Matlab	2	[61, 50]
		Java	1	[55]
3	Hybrid GA with other than Meta-heuristic Algorithms	Delphi	1	[20]
		C++	13	[68, 2, 13, 56, 81, 14, 83, 41, 33, 44, 11, 57, 18]
		C	4	[84, 63, 76, 59]
		Matlab	11	[71, 10, 80, 73, 66, 17, 25, 72, 69, 61, 42]
		Java	3	[30, 70, 47]
Delphi	1	[9]		

## 5.6 Various Graphical Representations for FJSSP

### 5.6.1 Directed Graph

A directed graph is a graph which contains a set of objects. These objects are combined together, where all the edges are going from one vertex to other. It is also sometimes called as a digraph. Undirected graph is a graph in which the edges are bidirectional [20]. In a digraph, the edge of a directed graph recovers each edge of a graph. A simple directed graph is a graph having no multiple edges or loops. A graph whose each edge is bi directed, is called as a complete graph. An oriented graph is a graph with no proper pair of directed edges. A tournament graph is a complete oriented graph in which all pair of nodes is merged by a particular edge which has a dissimilar direction [32].

### 5.6.2 Undirected Graph

A graph which contains set of objects connected together and whose each edge is bidirectional, is called as an undirected graph. It can also be known as an undirected network [46]. A directed graph is a graph in which all the edges point in a specific direction.

The Figure 5.9 represents the various graphical representations for Flexible Job Shop Scheduling.

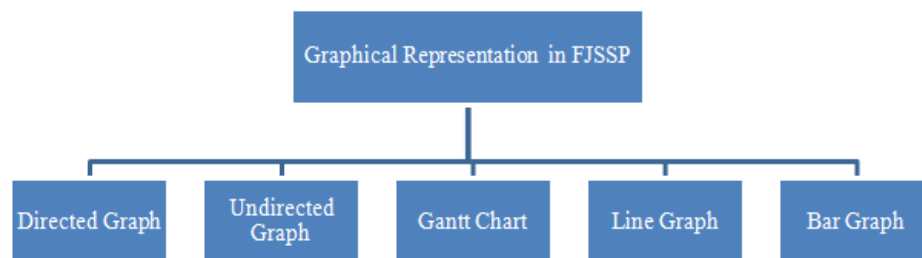


Figure 5.9 Graphical Representations for FJSSP

### 5.6.3 Gantt chart

It is a graphical illustration of a scheduling of the project. Begin and end dates of various elements of a project that involve tasks dependencies and milestones are represented by

the bar chart. Henry Gantt has developed the Gantt chart [20]. It is very effective in defining the sequence of tasks that need completion and planning a project [62]. A Gantt chart helps in scheduling, monitoring, managing definite tasks in a job. Moreover, these tasks can be easily visible on the vertical bar. These charts can be exploited in various manufacturing, development in software's buildings, supplies, tools for project management or any specialized software like Gantt ware supports in developing Gantt charts. Various plans or project status are communicated by managers. They ensure that whether the project is going on track.

#### **5.6.4 Line Graph**

A line graph commonly known as a line chart is a kind of chart used to visualize the value of something. A line graph is a graph, which changes regularly with time. It is a graphical illustration of data information. It can also be known as a line chart. To signify a continuous change, the data is connected by the points in a graph. Based on the data, the lines can descend or ascend. Various events, information and situations are evaluated by line graph [67]. It is created from the bar graph by locating a point at the top middle of each bar. The line graph comprises of a horizontal x-axis and a vertical y-axis. Most line graphs only handle with positive number values [51]. Thus, these axes usually intersect nearby the bottom of the y-axis and the left end of the x-axis. The line graph is an effective visual tool for finance, marketing. It is also beneficial in weather monitoring, laboratory research work or any function involving a correlation between two numerical values [52, 53]. However, if two or more lines are on the chart then it can be used as a analogy between them.

#### **5.6.5 Bar Graph**

It is a graphical illustration of statistical data in which the independent variable can achieve suitable distinct values. The dependent variable can be discrete or continuous. The vertical bar graph is the most common type of bar graph which can also called as a column graph [28]. To represent the comparison among various categories of data, bars are used. The horizontal or vertical bar graphs can be used. It consists of two axes. The categories are described by the one axis. Then, these categories are being compared. The

second axis will represent the values of the data. This axis should decide that what graph is exhibiting. The bar will be aligned vertically, if the values are onto the vertical axis. If they aligned horizontally then it means that they are on the horizontal axis [51].

The Table 5 shows the graphical representation used for Flexible Job Shop Scheduling approach. It contains various categories of graphs for FJSSP. Different types of graphs such as bar graph, Gantt chart, line graph, directed graph with their count, citations are also specified.

**Table 5 Graphical representations for FJSSP**

S. No.	GA approach	Graphical Representation	Count	Citation
1	Core Genetic Algorithm	Gantt Chart	23	[46, 1, 3, 48, 13, 12, 5, 7, 53, 54, 23, 27, 29, 79, 36, 44, 11, 16, 8, 25, 34, 24, 81]
		Line Graph	26	[46, 1, 82, 4, 71, 52, 12, 7, 53, 26, 54, 73, 23, 22, 43, 29, 30, 79, 36, 11, 8, 40, 57, 38, 51, 47]
		Bar Graph	9	[82, 4, 28, 52, 73, 27, 29, 34, 51]
		Directed Graph	3	[1, 33, 21]
2	Hybrid GA club with Meta-heuristic Algorithms	Gantt Chart	9	[20, 56, 14, 17, 37, 63, 62, 59, 55]
		Line Graph	5	[66, 63, 64, 65, 32]
		Bar Graph	2	[66, 64]
		Directed Graph	3	[20, 67, 56]
3	Hybrid GA with other than Meta-heuristic Algorithms	Gantt Chart	11	[46, 20, 9, 13, 56, 14, 17, 63, 70, 72, 42] [46, 56, 71, 84, 41, 17, 74,
		Line Graph	13	65, 32, 57, 72, 69, 51]
		Bar Graph	4	[13, 30, 69, 51]
		Directed Graph	4	[9, 68, 83, 74]

## Chapter 6

### Conclusion

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After going through the research contribution in the domain of Flexible Job Shop Scheduling and Genetic Algorithm, a detailed dissection has been provided to categorize the big domain into various sub- domains with explicit feature set.

Based on the set of research questions, data information was thoroughly drawn out from the prime studies and has been analyzed to solve the RQ's. The following data has been examined from the articles of research.

The key contributions of the work undertaken are given below:

- Study of different approaches for Flexible Job Shop Scheduling.
- Analysis of different parameters to classify these approaches into various groups.
- Segmentation of various existing algorithms/ techniques for the particular method in flexible job shop scheduling.
- Detailed categorization on the basis of different tools/ API's and Graphical constructs available for Flexible Job Shop Scheduling with Genetic algorithm.

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## Acronyms

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FJSSP	Flexible Job Shop Scheduling Problem
GA	Genetic Algorithm
JSSP	Job Shop Scheduling Problem
PGA	Parallel Genetic Algorithm
HGA	Hybrid Genetic Algorithm
MGA	Modified Genetic Algorithm
RKGA	Random Key Genetic Algorithm
SA	Simulated Annealing
PSO	Particle Swarm Optimization
FA	Firefly Algorithm
ACO	Ant colony optimization
CO	Combinatorial Optimization
ACS	Ant Colony System
VNS	Variable Neighborhood search
LS	Local Search
VND	Variable Neighborhood Descent
BA	Business Analytics
MOEA	Multi Objective Evolutionary Algorithm
NSGA	Non-dominated Sorting Genetic Algorithm
FL	Fuzzy Logic

# Thesis

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