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A Genetic Algorithm Approach for Process Planning and Scheduling in Job Shop Environment

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***Abstract*— Traditionally, scheduling and process planning are considered as two different functions in a manufacturing environment. In this paper we consider the simultaneous selection of best process plan and scheduling of jobs in a job shop environment. We propose a spreadsheet based genetic algorithm (GA) to solve this class of problem. The shop model is built in Microsoft Excel spreadsheet to find the optimized process plan and corresponding schedule. Benchmark problems already published in the literature have been taken to demonstrate the performance of the proposed algorithm. Results obtained from proposed approach are equal or better than the earlier studies. It is also shown that the proposed algorithm is general purpose and could be used to optimize any objective function without changing the model or the GA routine.**

***Index Terms* – Genetic Algorithm (GA), Process planning, Scheduling, Job Shop, Spreadsheet**

I. Introduction

Process planning and scheduling are two of the most important functions in manufacturing. Process planning function has many effects on the scheduling functions. Society of Manufacturing Engineers (SME) defines process planning as “the systematic determination of the methods by which a product is to be manufactured economically and competitively” [1]. Scheduling is the allocation of tasks to the available resources (material , labor or equipment) over a time period. The objective of scheduling is to satisfy various production constraints and maximize / minimize a desired objective function.

Process planning function provides a basic input to the scheduling function. Process planning emphasizes the technical requirements of a job, while scheduling concerns with the timing aspect of it. Thus it is in conflict with the scheduling function as the process planner does not have the view or control of the actual shop floor status. Therefore, traditionally, scheduling and process planning are considered as two different functions in a manufacturing environment. However, with the possibility of alternative machines, setups and processes to manufacture a particular part, the selection of plan in a manufacturing shop has become a critical problem.

When both scheduling and process planning are performed independently, the schedule that is produced lacks adaptability and flexibility, therefore in order to accomplish effective and realistic schedules due attention must be given to these two functions [2]. Moreover, alternative plans also enable allocation of tasks to other machines with added flexibility and thus reducing the possibility of the collision between a machine and a job.

The aim of this research is to integrate the process planning and scheduling functions to simultaneously generate a selected process plan and schedule for the jobs on available machines. We develop a genetic algorithm (GA) that functions as an add-in within the spreadsheet environment for minimizing the makespan or total completion for the jobs which may have multiple processing plans.

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II. Literature Review

The idea of integrating process planning and scheduling functions is a paradigm shift for most manufacturing organizations. Previous work on the use of alternative operations for a particular job reported that alternative plans lead to benefit in a manufacturing environment [3]-[5]. According to these papers, alternative plans can successfully be used for:

1) solving disruption problems on the shop floor, such as rush orders, machine overloads and machine breakdowns;
2) reduction of in-process inventory;
3) increasing equipment utilization.

Sundaram & Fu [6] were probably the earliest of the researchers who showed that to gain productivity improvements in manufacturing there was a need to integrate process planning and scheduling functions. Several researchers have also emphasized upon the concept to integrate process planning and scheduling in a job shop [2, 7-8]. The literature reports three major approaches for the integration of process planning and scheduling functions [9-10] are:

1) Non-linear approach
2) Closed-Loop approach, and
3) Distributed approach

Comprehensive reviews on the integration of process planning and scheduling has been provided by Li et al. [9], Phanden et al. [10] and Tan & Khoshnevis [11], Gen et al. [12].

III. PROBLEM & ASSUMPTIONS

In classic scheduling theory, scheduling of job in job shop belongs to NP-hard problems, therefore generally, process planning function is considered to be independent of the scheduling function. However, in the current research we have integrated process planning function with scheduling function. The problem thus becomes to choose the best process plan that minimizes the makespan for a set of jobs.

In the present study it is assumed jobs consist of ordered operations and are independent of each other. Each of the order and combination of operations defines the routing or a process plan. Although there may be alternate process plans for a job, however only one plan is to be selected to process the job. Some of the underlying assumptions used in the study are:

1) Preemption of job is not allowed.
2) All jobs are simultaneously available at time zero.
3) Each operation has a definite processing requirement and an operation time.
4) After a job has finished processing on a particular machine it is immediately moved to the next machine. The time required for the movement or transportation for the job between the machines is included in the processing time and thus assumed to be negligible.
5) Set-up time for a particular operation is not sequence dependent and is included in the processing time.

IV. GENETIC ALGORITHMS

Genetic Algorithms (GA) belong to a stochastic class of problems inspired from the process of natural evolution. GAs were first introduced by Holland [13] at University of Michigan, USA in 1970s. GAs begins with a population of solutions called chromosomes. Two solutions are then selected as parents to perform the crossover operation. In the crossover process the information between the two parents is swapped to produce one or more child solutions. In the next step, mutation process is performed that randomly modifies some genes within the chromosome. The whole process is guided by the principle of survival of the fittest. The search proceeds until a specified stopping criterion is reached. For each successive generation the fitter solutions are selected to form a new population. A comprehensive introduction along with various applications has been provided by Goldberg [14].

The earliest GA application to process planning and scheduling has been reported by Candido [15]. Since then many other researchers have also applied GAs for integrated process planning and scheduling problem [16]-[38].

In this research a commercial GA package Evolver [39] has been used. The software functions as an add-in to Microsoft Excel spreadsheet. Spreadsheet's built in functions are used to develop the job shop model for integrated process planning and scheduling. The process plan, constraints, variables and objective function are defined in the corresponding cells of the spreadsheet. Fig. 1 shows the Evolver-Microsoft Excel architecture. Population of solutions is generated in the spreadsheet environment, which after crossover and mutation operations are passed back to the model as the fittest solution. Upon reaching the stopping criteria, the model gives the best solution back to the spreadsheet.

Another advantage of using the spreadsheet environment for the current application was its familiarity by a common user on the shop floor and are used widely in manufacturing industry, because they are very easy to use, quick to adapt or create, and easy to modify. The logical arrangement of data in a tabular form makes it convenient for a shop floor worker to understand the problem. Moreover, the charting and what-if-analysis functions of spreadsheet allow the user to better visualize the problem.

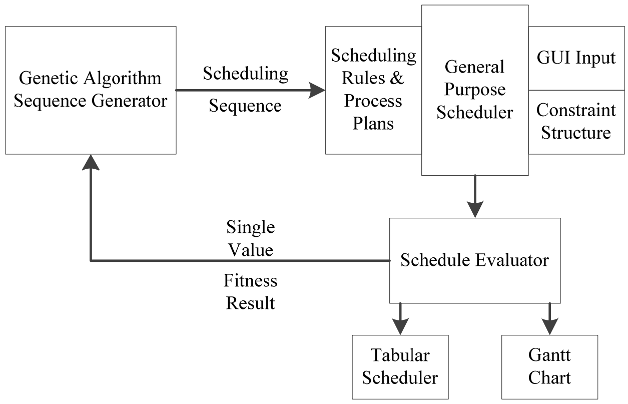

Fig. 1: Evolver-Microsoft Excel architecture

A. *Chromosome Representation*

For integrated process planning and scheduling problem, chromosome representation is as shown in Fig. 2.

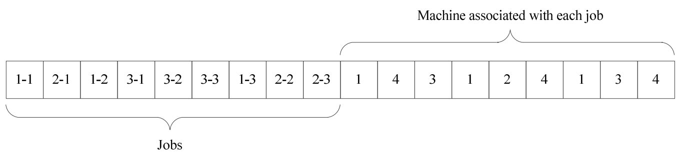

Fig 2: Chromosome representation for integrated process planning and scheduling

The chromosome represents three jobs each having three operations to be performed in a job shop to be processed on four machines where each of the operation can be processed on more than one machine. The first nine genes represent the job-operation. 1-1, 2-1, 1-2 would be read as job 1-operation 1, job 2-operation 1 and job 1-operation 2 respectively. Task 1-2 would follow 1-1 and similarly for other instances, there are pre-defined precedence constraints. Next nine genes represent the machine associated with each job-operation combination and would be read as follows: task 1-1 to be processed on machine 1; task 2-1 on machine 4; task 1-2 on machine 3; task 3-1 on machine 1; task 3-2 on machine 2 and so on.

Each entity of the chromosome in Fig. 2 is computed at a different location whithin the spreadsheet, and finally linked together to calculate the desired objective function, which in this research is the makespan or the total completion time for a set of jobs.

B. *Crossover & Mutation Operators*

First nine genes of the chromosome i.e. job-operation combination requires permutation representation where the order of the genes is to be determined keeping in view the precedence constraints. For this purpose we use the "Order Solving Method" which incorporates Order crossover operator [40]. While for the machine assignment i.e., the last nine genes, a random number from among the machines that are available to process that task is generated. For this we use "Recipe Solving Method" is used that incorporates Uniform crossover operator [40].

"Order Solving Method" performs mutation by swapping some genes by changing their position in the chromosome; this is to preserve the original values. The number of swaps decreases or increases proportionate to the decrease or increase of the mutation rate. In the "Recipe Solving Method", the mutation is performed by looking at each individual gene. A random number between 0 and 1 is generated for each gene in the chromosome, and if a gene gets a number that is less than or equal to the mutation rate (for example, 0.06), then that gene is mutated. Mutating a gene involves replacing it with a randomly generated value (within a valid min-max range).

V. EXPERIMENTAL ANALYSIS

A. *Implementation of Algorithm*

The job-operation order (first nine genes) in Fig. 2 is a list of jobs where our aim is to find the optimum way to logically arrange a set of given jobs keeping in view the precedence constraints. The permutation of job-operation combination is independent of assignment of task to the machine. However, the resultant objective function value is computed considering all the constraints.

For the machine assignment corresponding to each job-operation combination, i.e., for genes 9-18 (Fig. 2), a random integer number is generated by the algorithm considering all the constraints that have initially been defined in the model. Constraints are set of conditions that must be met for a solution to be valid. In this particular scenario, the constraints for the jobs are the precedence constraints, while for the machine corresponding to each job, it is an integer number that is to be selected from among the available machine which in this case are numbers like 1, 2, 3……… etc.

B. *Computational Analysis*

Set of problems already published in the literature have been used to demonstrate the effectiveness and quality solution found by the proposed approach. All simulations were run on a Dual Core 2.10 GHz computer with 4 GB RAM.

The first instance has been taken from Nasr and Elsayed [7]. The instance consists of four jobs each having three operations to be processed on six machines. There may be multiple machines to process any one operation. The job shop data is given in Table 1:

Table 1 Problem data for Nasr and Elsayed [7]

Job No	Operation No	Alternative Machines					
		1	2	3	4	5	6
Job 1	O_{11}	2	3	4	-	-	-
	O_{12}	-	3	-	2	4	-
	O_{13}	1	4	5	-	-	-
Job 2	O_{21}	3	-	5	-	2	-
	O_{22}	4	3	-	-	6	-
	O_{23}	-	-	4	-	7	11
Job 3	O_{31}	5	6	-	-	-	-
	O_{32}	-	4	-	3	5	-
	O_{33}	-	-	13	-	9	12
Job 4	O_{41}	9	-	7	9	-	-
	O_{42}	-	6	-	4	-	5
	O_{43}	1	-	3	-	-	3

The result of the heuristic procedure developed by Nasr and Elsayed [7] is compared with the proposed GA. Nasr and Elsayed's heuristic gives an average flow time of 12.25 with flow time of each job as 7, 11, 18 and 13 respectively, however, proposed GA finds a mean flow time of 11.75 with flow time for job 1, 2, 3 and 4 as 6, 11, 17 and 13 respectively.

The second instance has been adopted from Lee et al. [20]. The instance consists of eight jobs to be processed on six machines with a total of twenty operations. The precedence relationship of the jobs is shown in fig. 3.

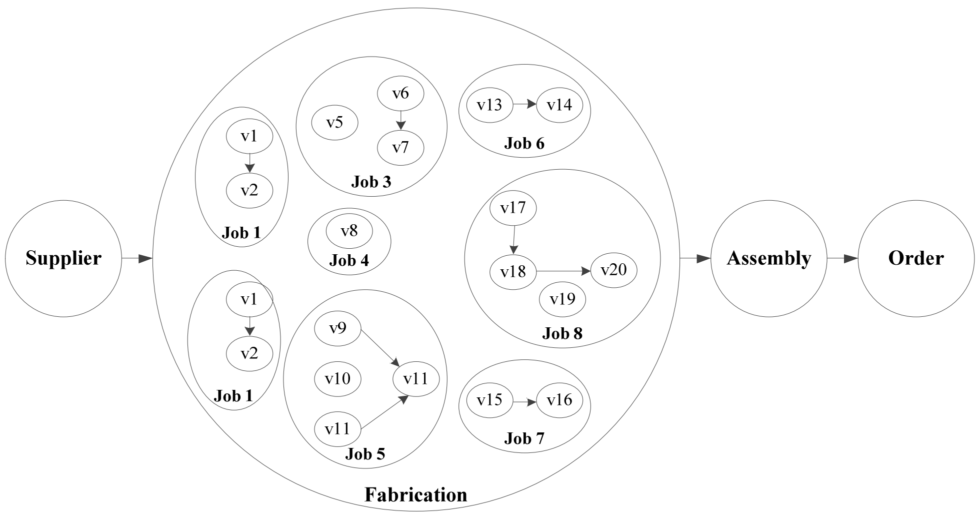

Fig 3. Precedence relationship diagram for instance 2

The proposed GA obtained a value of 23 for the makespan for instance 2. The makespan for the same problem reported by Lee et al. using GA [21], Chan et al. using artificial immune system based fuzzy logic controller [41], Li et al. using hybrid algorithm [43], Palmer using simulated annealing [43] and Amin-Naseri using hybrid GA [38] was 34, 26, 24, 30, and 23 respectively. The resulting Gantt chart is given in Fig. 4.

Third instance has been adopted from Lee and DiCesare [44]. The instance consists of five jobs to be processed on three machines. The objective is to minimize makespan. The results reported by Lee and DiCesare using petri-net based method [44], Kumar et al. using ant colony optimization (ACO) [45], Leung et al. using ACO [46], Chan et al. using GAs [47] and Leung et al. [48] were 439, 420, 390, 360 and 380 respectively. The proposed GA approach obtained the makespan value of 360 for the same problem.

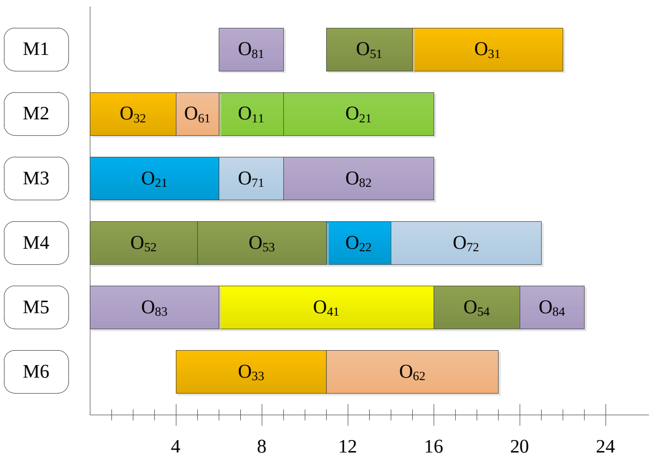

Fig. 4 Gantt Chart for instance 2

VI. CONCLUSION

In this paper we presented a GA approach for integrated process planning and scheduling. The general purpose GA routine is an add-in to the Microsoft Excel. The proposed approach uses a general purpose GA algorithm. The model incorporating the constraints on a shop floor is implemented in the spreadsheet model. Comparison with earlier studies shows that the performance of the proposed algorithm is superior to the previously reported results.

Logical arrangement of data in the form of tables within the spreadsheet environment enables a user to carry out instant what-if analysis. Moreover, any objective function could be used without either changing the shop model or the GA routine. Additionally the model can very be easily customized to include additional constraints, machines, jobs etc. as the case may be.

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