Integration of Process Planning and Job Shop Scheduling Using Genetic Algorithm

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Abstract: - This study focused on the integration problem of process planning and scheduling in a job shop environment. In an effort to integrate process planning and scheduling by taking advantage of the flexibility that alternative process plans offer, we have designed a GA (Genetic Algorithm)-based scheduling method. The performance of this newly suggested GA-based method has been evaluated by comparing integrated scheduling with separated scheduling in a real company that has alternative process plans. Also, a couple of benchmark cases have been tested for performance evaluation, thus proving that the integrated scheduling shown by this research can be effectively applied to the real case.

Key-words: - Integrated Scheduling, Genetic Algorithm, Job Shop

1 Introduction

Scheduling has to consider operations sequences, machine load and availability of machines. This means that scheduling is based on predetermined process planning. Process planning determines the manufacturing process routing and acts as a bridge between product design and manufacturing. That is, it is a process of allocating resources and operations for manufacturing of products. Process planning and production scheduling activities in a job shop are closely related to each other, but typically they have been handled independently. Process planning has been done without considering the current capacity of the shop in terms of effective use of resources. Also, scheduling has been performed without regard to the opportunities that alternative process plans can provide for acceleration of production flows.

In scheduling, an alternative process plan enables the allocation of operations to other machines with flexibility of, thus reducing the possibility of the collision between a job and a machine. Weintraub et al. [12] suggested a tabu search algorithm for scheduling problem that includes an alternative process plan to minimize lateness. By applying this method to diverse cases, they proved that jobs with alternative process plans enable to produce better result of an objective function. In reality, the separation of process planning and scheduling can cause long lead-time, production cost increase, and lateness. However, simultaneous consideration of process planning and scheduling creates much more complex scheduling problem, which is also an NP-complete problem [7]. Because of this complexity, it has not attracted the attention of researchers.

Recently, there are ongoing researches in an effort to include alternative operations sequences and alternative machines in the scheduling. Conducting process planning and scheduling at the same time, while considering of various possible alternative resources and operations sequences, is called “integrated process planning and scheduling” [10]. The scheduling problem that has alternative process plans and the flexible job shop problem are included in the integration problem. The integration enables the most effective use of production resources without causing frequent changes in the process planning through considering process planning and scheduling as one optimization problem.

Khoshnevis and Chen [7] and Huang et al. [6] discussed the basic issues and methodology involved in the integration of process planning and scheduling. Palmer [10] suggested a simulated annealing approach to integrated scheduling, thus producing a better solution than that of Khoshnevis and Chen. Brandimarte and Calderini [3] suggested a hierarchical approach to deal with the integration problem with priority constraints of operations and several alternative process plans. The upper level deals with process selection, and the lower level deals with job shop scheduling. Their levels are represented in a linear mixed-integer programming model. Brandimarte [2] proposed a hierarchical tabu search structure to solve the flexible job shop problem. For the objective of minimizing makespan, the routing and scheduling problem is solved by dispatching rules. Then the schedule obtained is refined by the tabu search algorithm. Nasr and Elsayed [9] and Kim and Egbelu [8] also stressed the necessity of integrated process planning and scheduling in a job shop environment. However, these studies considered specific alternative process plans because of the complexity of overall optimization. Nasr and Elsayed considered alternative machines for each operation in scheduling jobs, but each job had a single operations sequence. Kim and Egbelu proposed a mixed-integer programming model for scheduling jobs having multiple process plans. In this approach, possible process plans for each job were given and fixed. Thus all the plans should be decided before scheduling. They presented a methodology which can effectively handle many process plans for each job in solving the integrated process planning and scheduling.

In this paper, we propose a GA to minimize the makespan of each order in the integration problem with alternative machines and alternative operations sequences.

2 Genetic Algorithm for Integrating Process Planning and Scheduling

2.1 Design of Genetic Algorithm

GA enables us to seek a better solution in multiple approaches with a large number of individuals in a population. The most critical point in designing integrated process planning and scheduling method based on GA is to develop a representation scheme of chromosome representing the feasible solution in consideration of multiple plans as well as satisfying many constraints. Also, a proper objective function, composition method of population, genetic operator and genetic parameter should be designed according to specific properties of the problem. The procedure of the GA used in this study has followed the proved procedure in previous paper [11], and the chromosome representation, genetic operator and objective function have been revised to deal with the integration problem.

2.2.1 Representation

To solve an integrated process planning and scheduling problem through GA, The solution of the integration problem considering alternative machines and operations sequences should first be represented in chromosome. The represented chromosome can help to find a better combination of operations sequence and alternative machine for each operation per job in evolution process. It makes GA can solve the integration problem.

To represent the chromosome, we base on an operation-based representation that uses an unpartitioned permutation with m-repetitions of job numbers [1]. It is a pattern of repeating job number as many times as its number of operations. Each gene represents one operation and it is assigned to machines in the represented order. For example, a problem involving three jobs and three machines, as shown in Table 1, is represented in sequence in Fig. 1. In the figure, each number in the first row is the job number. Each job number is repeated three times in the first row because each job has three operations. The first job number represents the first operation of the job, and the second represents the second operation. The order of genes in the chromosome represents the order in which the operations of jobs are scheduled. As long as the job number appears as many times as the number of operations, this chromosome will always maintain its feasibility.

3	2	2	2	3	1	1	1	3	
2	3	3	3	2	1	1	1	2	
3	2	2	1	1	2	1	1	2	
(1	*1*	*2*	*3*	*2*	*1*	*2*	*3*	*3)*	(Index)

Fig. 1. Chromosome representation

The second row in Fig. 1 is for random numbers used to determine alternative operations sequences. As each job is completed in one operation sequence, a random number is produced for each job within the number of maximum alternative operations sequences. For example, as Job 2 in Table 1 has three alternative operations sequences, the random number has to be produced within the range of 1-3. The third row has the random numbers representing alternative machines. Table 1 shows that the second operation of Job 1 is to be done by M2, but it can also be done by either M1 or M3. In this example, there are three machines that can handle the second operation of Job 1. As there are no more alternative machines, as shown in Table 1, the random numbers for all alternative machines will be produced within the range of 1-3. The index shows the ordinal operation of each job.

Table 1. Alternative machines and alternative operation sequences for each Job

Job	Operation number	Machine number, Processing time	Alternative machine, Processing time	Operations sequences
1	□	M1, 6	M2, 6	□→□→□ □→□→□
	□	M2, 5	(M1, 6), (M3, 6)	
	□	M3, 4		
2	□	M1, 3	M3, 4	□→□→□ □→□→□ □→□→□
	□	M2, 7		
	□	M3, 6	(M1, 6), (M2, 7)	
3	□	M1, 7	M3, 8	□→□→□ □→□→□
	□	M3, 5	(M1, 5), (M2, 6)	
	□	M2, 4		

The bold 3 in the first row in Fig. 1 means the first operation of job 3, and the bold 2 in the second row means the operation sequence for job 3. Accordingly, this means that the second alternative operations sequence is □ → □ → □. And the bold 3 in the third row means that the first operation, □ of job 3 is allocated to the third alternative machine among alternative machines. However, since this case has two alternative machines, it is to be allocated to the first machine, M1. If there is no alternative machine corresponding to the random number for choosing an alternative machine, the first machine is to be allocated.

Makespan will be measured by allocating each operation to the machines in the order of the first row.

2.2.2 Selection Method

Superior animals are mostly used as seed animals to bring forth the young at domestic animal breeding farms. Seed selection, a method of individual selection used in the propagation of cattle and preservation of an individual, has been introduced to the evolution of GA [11]. If the random value generated between 0 and 1 for an individual belonging to the father is smaller than 0.9, the good individual will be selected within a seed size involving superior individuals in the ranking population. Otherwise, the individual will be randomly selected from the entire group. The mother will be selected randomly from the entire group. Those selected will be used as parents, and then returned to the individual group so that they can be used again later.

2.2.3 Genetic Operator

The crossover operator should maintain and evolve a good order relationship of chromosomes. In this research the crossover operator first produces a random section and then inserts all the genes inside the section into parent 2. The position of insertion is just before the gene where the random section starts. For example, in parent 1 if the random section starts in the fourth place, then the position of insertion will be before the fourth gene in parent 2. Then all genes with the same index as the genes in the random section will be deleted in parent 2. To make the alternative operations sequences coincide with the same job number, it will be corrected according to the alternative operations sequence of the initial job number. These processes will be performed by alternating parent 1 and 2, thus producing two children. After two offspring are evaluated, the better one will be sent as the next generation. The crossover operator has shown good performance in a previous study [11].

The mutation operator brings a change to the chromosome, thus maintaining diversity within the group. This research uses the mutation operator based on the neighborhood searching method [5].

2.2.4 Fitness Function and Replacement

The minimum makespan in scheduling often means the highest efficiency of a machine. When a chromosome is represented as a permutation type, the makespan is produced by the process that assigns operations to the machines according to the sequence of genes from left to right. This operation is performed while maintaining the technological order of jobs and considering alternative operations sequences and alternative machines. Also, the release time of each job and available time of each machine has been considered.

The next generation will be formed by selection among the current generation with a help of the genetic operator. The new individuals will be produced as many as the number of initial population and they form the next generation. By using elitism, bad individuals will be replaced with good individuals. Also, because of the crossover rate and mutation rate, some individuals move to the next generation without getting through the genetic operator.

3 Evaluation of Performance

In order to evaluate the performance of the GA developed in this study, we used an example of a molding company, a typical job shop that has multiple process plans. Through this real case, we have compared two kinds of scheduling results, that is, the integrated scheduling considering the alternative machines and operations sequence and the traditional scheduling considering them sequentially. We used the representative job shop problem with alternative machines and integration problem of process planning and scheduling for the performance evaluation of the GA. We also used makespan as an objective function for comparing with prior researches of integration problem.

In the experiment, the parameters - crossover rate (0.8), mutation rate (0.1), seed size (20) and elitism size (10) - were decided by experiment. Population size and generation number are 200 and 1000 respectively. We look for the best results based on 50 runs in each benchmark problem.

3.1 An Example of Integration Problem

First, we deal with the example of an injection molding company which is a typical job shop. A molding is designed based on the customer's order, and then its process planning is made to produce the goods. In order to produce one product, a lot of parts are necessary, and one part is considered as one job. One job has several operations, and some of these operations have no precedence constraints. For example, in the Elbow product of the Table 2, the two operations in job 2 can be done without precedence constraints. The shaded operations in Table 2, Table 3 and Table 4 have no precedence constraints. In particular, in job 5 of Table 2, MM operation is to be done prior to RD operation, but NCL operation can be done before MM operation or RD operation. That is, there are three alternative operations sequences. Some operations have alternative machines. There are three units of MM machine and two units of E machine in this case. Table 2, Table 3 and Table 4 show the process plans where their alternative machines and alternative operations sequence were decided by several tests. It is process plans producing the best makespan among the several process plans in considering process planning and scheduling separately.

Table 2. Process planning of "Elbow" product

Job	Operation sequence (processing time)					
1	MM2 (20)	RD (15)				
2	MM1 (20)	RD (10)				
3	LM (16)	MM3 (30)	RD (12)			
4	LM (30)	MM2 (30)	RD(12)			
5	MM1 (18)	RD(3)	NCL (4)	E1 (20)	SF1 (10)	L(10)
6	MM2 (30)	RD(12)	L(10)	E2 (20)	SF1 (15)	
7	MM3 (5)	E1(4)	SF1(6)	L(10)	RD(5)	

Table 3. Process planning of "Picnic Case" product

Job	Operation sequence (processing time)				
1	LM (14)	RD(17)			
2	LM (14)	RD(5)			
3	MM1 (4)	RD(8)			
4	RD(2)	MM1(1)			
5	MM2 (6)	RD(2)			
6	MM3 (4)	RD(6)	NCM(15)	E1(8)	SF1(10)
7	MM2 (5)	RD(6)	NCM(17)	E2(12)	SF1(10)
8	MM3 (3)	RD(4)	NCM(8)	E1(3)	SF1(5)
9	MM1 (10)	AS(2)	SF1(3)		

Table 4. Process planning of "Cake Box" product

Job	Operation sequence (processing time)				
1	LM(18)	RD(20)			
2	LM(17)	RD(10)			
3	MM1 (6)	RD(2)			
4	MM1 (6)	RD(2)			
5	MM2 (4)	RD(7)	E1(4)	NCM (19)	SF1 (10)
6	MM2 (4)	RD(8)	E2(4)	NCM (25)	SF1 (10)
7	MM3 (22)	RD(4)	E1(3)	SF2(5)	

We look for the best results based on 10 runs in this case. Table 5 shows the makespan obtained by separated scheduling and integrated scheduling of process planning and scheduling. Here, one can clearly see the improved makespan in the integrated scheduling. Since there are many solutions with the same value in the final population of GA, we have not suggested the final process plan.

Table 5. Comparison of integrated scheduling results

Product	Makespan	
	Non-Integration	Integration
Elbow	92 hours	88 hours
Picnic Case	65	62
Cake Box	69	61

3.2 Chambers' Problem with Alternative Machines

To test the performance of the GA proposed in this study, we have used the alternative machine problem that had already been proven. In an effort to examine the performance of an algorithm used in a job shop with alternative machines, Chambers [4] has added the specific machine according to the simple criterion in the benchmark problem of a classic job shop. He has revised an MT10 problem for making an alternative machine problem. The criterion is the sum of required processing times for each machine. The rule to add an alternative machine is as follows.

P1: the machine requiring the greatest processing time is replicated once
P1, P1: the machine requiring the greatest processing time is replicated twice
P1,P1,P1:the machine requiring the greatest processing time is replicated three times
P1, P2: the machine requiring the greatest, second-greatest processing time is replicated once each

Table 6. Results of Alternative Machine Problem through Revised MT 10 Problem

Problem	Dispatching	Chambers' Tabu search	Proposed GA
P1	1023	929	929
P1,P1	1023	929	929
P1,P1,P1	1023	936	929
P1,P2	982	913	909

As shown in Table 6, the newly suggested GA is showing a better solution.

4 Conclusion

A critical point in the manufacturing company is to calculate exactly the possible completion time estimates for the orders of customers. To this end, selection of operations sequence for each job, selection of machine for each operation and scheduling for each machine are to be carried out simultaneously and synthetically. The integration of process planning and scheduling significantly reduces the trial and error and repeated re-plan resulting from the separated scheduling.

This study tried to develop a GA for integration of process planning and scheduling, and to show the possibility of improving makespan. Also, we have produced the optimal or improved solution for the job shop problem that has alternative operations sequences and alternative machines, thus proving the performance of the GA. This means that we can more effectively respond to the due date demanded by customers.

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