Multi-objective Reactive Scheduling Based on Genetic Algorithm

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Abstract

A genetic algorithm based reactive scheduling method was proposed in the previous research, in oder to modify and improve a disturbed initial production schedule without suspending the progress of manufacturing process. This paper proposes a new crossover method to improve the performance of the reactive scheduling method for total tardiness minimization problems and total flow time minimization problems. A multi-objective reactive scheduling method is also proposed based on the reactive scheduling method improved in this research. A prototype of multi-objective reactive scheduling system is developed and applied to computational experiments for job-shop type scheduling problems.

1 Introduction

It is assumed, in the traditional scheduling researches, that manufacturing environments are stable and controllable. However, unscheduled disruptions, such as delays of manufacturing operations, inputs of additional jobs and failures in manufacturing equipment, often occur in the agile manufacturing systems. If the disruptions occur during the progress of manufacturing process, the initial production schedule is disturbed and the manufacturing system cannot satisfy the predetermined constraints on the make-span and the due dates. Therefore, a systematic scheduling method is required to modify the disturbed initial production schedule to cope with the unforeseen disruptions in the agile manufacturing systems.

Several scheduling methods have been proposed to cope with the disruptions in the manufacturing systems. The proposed methods are basically classified into two types. They are, real-time scheduling and reactive scheduling. Most of the existing researches on the real-time scheduling use the heuristic rules, such as FCFS, SPT and MWKR, to select the next job to be manufactured, when manufacturing equipment finishes its present job in the manufacturing system [1]-[2]. There are still some remaining problems in the existing real-time scheduling methods from the viewpoint of the optimization of the production schedules. The reactive scheduling method modifies the predetermined initial production schedule, when unscheduled disruptions occur in the manufacturing system [3]. The existing reactive scheduling methods are not enough to generate optimal production schedules during the progress of manufacturing process.

The previous research proposed a Genetic Algorithm (GA) based reactive scheduling method [4]. The proposed reactive scheduling method can modify and improve the disturbed initial production schedule without interrupting the manufacturing processes, when unscheduled disruptions occur in the manufacturing system and the production schedule cannot satisfy the given due-date of products.

This paper deals with a new crossover method to improve the performance of the GA based reactive scheduling method for the total tardiness minimization problems and the total flow time minimization problems. The multi-objective reactive scheduling method is also proposed based on the reactive scheduling method improved in this research. A prototype of reactive scheduling system is developed and applied to the multi-objective reactive scheduling problem of the total tardiness minimization and the total flow time minimization.

2 Reactive Scheduling Method Using GA

2.1 Reactive Scheduling Concept

The reactive scheduling process is activated, only when unscheduled disruptions occur during the manufacturing process. It is necessary to consider the progress of manufacturing process in the reactive scheduling process.

It is assumed in this research that the reactive scheduling process improves the disturbed production schedule, without suspending the progress of manufacturing process. Figure 1 shows the whole reactive scheduling process proposed in this research. The reactive scheduling process is activated at the present time T_1, only when some unscheduled disruptions occur and the predetermined production schedule does not satisfy the given constraint. It is assumed that the reactive scheduling process takes computation time dt to generate new feasible schedule. Therefore, the schedules of the operations starting before ($T_1 + dt$) cannot be modified through the reactive scheduling process.

A modified production schedule is applied to the manufacturing system, if the modified production schedule is better than the current production schedule. When the newly generated production schedule does not satisfy the given constraint, the reactive scheduling process is activated continuously until new production schedule satisfies the given constraints, or until all the manufacturing operations have already started.

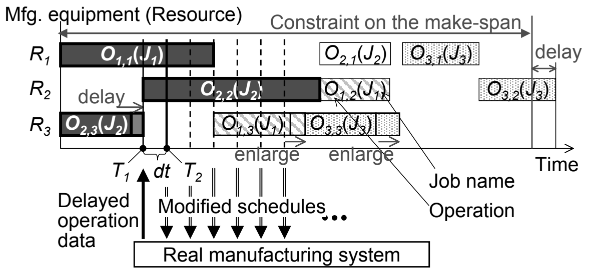

Fig. 1. Reactive scheduling process

2.2 Basic Reactive Scheduling Method Using GA

The proposed reactive scheduling method uses GA to improve the disturbed initial production schedule [4]. The GA is a probabilistic search technique based on the evolution mechanism [5]. The algorithms start with a population of parent individuals from which offspring are generated. Each individual has a chromosome, and it is evaluated based on a fitness value.

A production schedule is represented as a chromosome in the GA based scheduling method. The genes in the chromosome represent the job names of the operations to be completed. The job names are allocated to an array in the order of the execution sequence of the operations, as shown in Figure 2. This array of the job names represents the chromosome of the first individual. Other individuals in the initial population are randomly created by changing the positions of the genes of the first individual. The number of the individuals in the initial population equals to the population size s.

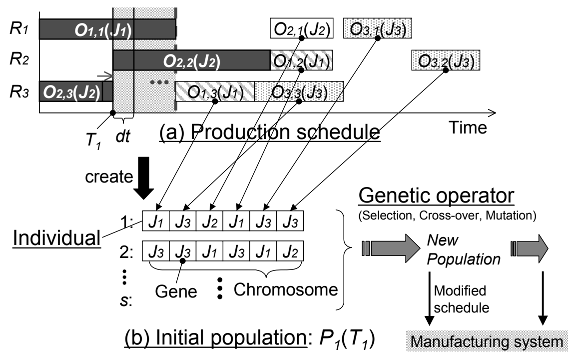

Fig. 2. Generation of initial population using GA

A fitness value, such as the value of make-span, total tardiness and total flow time, is evaluated for each individual. Based on the fitness value, genetic operators, such as selection, crossover and mutation, are applied to the individuals, in order to create new individuals representing the modified production schedules. The current schedule of the manufacturing system is replaced by the new schedule. If the improved schedule does not satisfy the constraint on the make-span, the genetic operators are applied to the individuals. The reactive scheduling processes are repeated until new production schedule satisfies the given constraints, or until all the manufacturing operations have already started.

3 Advanced Crossover Method

A new crossover method is proposed, in this research, to generate suitable individuals faster than the basic reactive scheduling method using the conventional crossover method. The conventional crossover method exchanges all the genes between two crossover points, which are randomly selected in two parent individuals, and generates two offspring individuals. The new crossover method exchanges genes of two individuals in consideration of the dominance and recessiveness of genes from the viewpoint of the objective functions, such as the total tardiness and the total flow time.

3.1 Evaluation of Genes for Tardiness Minimization

The total tardiness of jobs is calculated by using the following equation.

$$\sum_{i=1}^{n} \max(0, C_i - dd_i) \tag{1}$$

Where,

C_i : completion time, which represents maximum value of the finishing time of the job J_i.

dd_i : due date of the job J_i.

n : total number of jobs.

When the k-th gene is decoded to the h-th operation of job J_i, the lower bound of the finishing time of the operation is estimated for the k-th gene of the individual by using the following equation.

$$Lb_k = \left(ft_i^{(h)} + \sum_{s=h+1}^{n} pt_i^{(s)} \right) - dd_i \tag{2}$$

whrere,

$ft_i^{(h)}$: finishing time of the h-th operation of the job J_i.

$pt_i^{(s)}$: processing time of the remaining operations of the job J_i.

If the value of Lb_k is more than 0, it is impossible for the job J_i to finish the remaining operations by its due date. Therefore, the evaluation value for the recessiveness of genes is defined for the tardiness minimization problem as the following equation.

$$Rc_k = \begin{cases} 0 & (Lb_k \le 0) \\ 1 & (Lb_k > 0) \end{cases} \quad (3)$$

3.2 Evaluation of Genes for Flow Time Minimization

The total flow time of jobs is defined by the following equation.

$$\sum_{i=1}^{m} (ft_i^{(n)} - st_i^{(1)}) \quad (4)$$

Where,
$ft_i^{(n)}$: finishing time of the last operation of the job J_i.
$st_i^{(1)}$: starting time of the first operation of the job J_i.

The waiting time of the *h*-th operation of the job J_i is defined by the following equation.

$$wt_i^{(h)} = st_i^{(h)} - ft_i^{(h-1)} \quad (5)$$

Where,
$st_i^{(h)}$: starting time of the *h*-th operation of the job J_i.
$ft_i^{(h-1)}$: finishing time of the (*h*-1)-th operation of the job J_i.

The decrease of the waiting time makes the flow time of the job short in the production schedule. Therefore, the waiting time of each operation is compared with the average waiting time of operations for all the jobs, in order to evaluate the recessiveness of gene in the individual. When the *k*-th gene is decoded to the *h*-th operation of job J_i, the evaluation value for the recessiveness of genes is defined as the following equation for flow time minimization problems,

$$Rc_k = \begin{cases} 0 & (wt_i^{(h)} \le wt_{ave}) \\ 1 & (wt_i^{(h)} > wt_{ave}) \end{cases} \quad (6)$$

Where,
wt_{ave} : average waiting time of operations of all the jobs.

3.3 Exchange of Genes in Crossover Process

Two crossover points are randomly selected in two parent individuals. The individuals exchange the genes between the crossover points with each other. The advanced crossover method proposed in this research changes only the recessive genes, which have the evaluation value of 0. The rest of genes are inherited to offspring individuals as the dominant genes, which have the evaluation value of 1.

The genes whose job names are same as the job name of the allele are searched from the front of the former crossover point as the candidate of the gene to be exchanged, since the jobs allocated former in the individual are executed earlier than the ones allocated latter. The position of the gene is exchanged with the one of the genes selected from the candidate, as shown in Fig. 3.

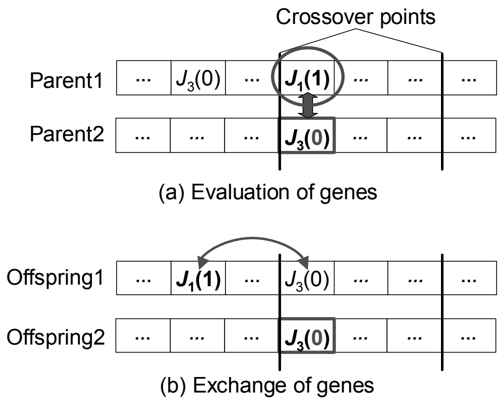

Fig. 3. Crossover process

4 Multi-objective Reactive Scheduling

4.1 Advanced Crossover for Multi-objective Problem

More than one objective function is simultaneously considered in the multi-objective scheduling problems. The combination of the evaluation values for recessiveness of gene is discussed in this section for the multi-objective reactive scheduling problems.

If *p* kinds of objective functions are considered in the reactive scheduling problems, each gene has p evaluation values for recessiveness of gene. The advanced crossover method changes the recessive genes, which have more than one evaluation value of 1, and inherits the dominant genes, which have all the evaluation value of 0, to offspring individuals.

In case of the combination of the total tardiness and the total flow time, the genes whose job names are same as the job name of the allele are searched from the front of the former crossover point as the candidate of the gene to be exchanged. The position of the gene is exchanged with the one of the genes selected from the candidate.

4.2 Multi-objective Reactive Scheduling Process

The multi-objective reactive scheduling processes consist of the following five steps.

Step 1: Setting up of present time Ti
The present time T_i (i=1, 2, ...) is set up.

Step 2: Estimation of computation time dt
The computation time *dt* is the time in which GA creates a new generation of the populations representing the modified production schedules. The time *dt* is estimated based on the time needed to generate a new population in the GA based initial production scheduling process, and it is modified based on the time for creating the modified production schedules through Step 3 to Step 5.

Step 3: Creation of initial population
Two cases are considered in the creation of the initial population constituted of the individuals.

Step 3-1: First activation of the reactive scheduling process
In case of the first activation of the reactive scheduling process at time T_1, the reactive scheduling system has only the initial production schedule. Therefore, the reactive scheduling process generates the initial population based on the initial production schedule as shown in Figure 2. The first individual is generated by allocating the job names of the operations starting after ($T_1 + dt$) to an array. Other individuals in the initial population are randomly created by changing the positions of the job names of the first individual.

Step 3-2: Second or later activations of the reactive scheduling process
In case of the second or later activations of the reactive scheduling process at time T_2 or later, the reactive scheduling process can inherit the population created in the previous reactive scheduling process. In other words, the last population of the previous reactive scheduling process can be the initial population. Two cases are considered for the inheritance process of the population as shown in the followings.

Case-A: No operations start between Ti and (Ti + dt)
If no operations start between T_i and ($T_i + dt$), all the individuals of the last population of the previous reactive scheduling process are inherited to a new reactive scheduling process between T_i and ($T_i + dt$).

Case-B: Some operations start between Ti and (Ti + dt)
If some operations start between T_i and ($T_i + dt$), the production schedules of these operations should be fixed. Therefore, a new reactive scheduling process can inherit only the individuals, which are consistent with the schedules of the fixed operations, from the last population created in the previous reactive scheduling process. The other individuals are deleted, and new individuals are randomly created from the inherited ones.

Step 4: Creation of next population
All the individuals in the population created in Step 3 are evaluated, and applied the genetic operators, such as selection, crossover and mutation, in order to create new individuals of the next population.

Step 4-1: Pareto rankings
The pareto ranking method proposed by Goldberg [6] is used to provide the rank for the individuals in the population. All non-dominated individuals have same rank, which represents equal probability of being selected. Non-dominated individuals in the population are firstly assigned rank 1 in the ranking process. Then, the individuals having rank 1 are removed from a set of candidates of individuals. The ranking method gives rank 2 to non-dominated individuals in the remaining individuals and removes them from the candidates. This ranking process is repeated, until all the individuals in the population are assigned the rank.

Step 4-2: Application of selection operator
Based on the rank, the selection operator is applied to the individuals of the population created in Step 3. All of the individual having rank 1 are selected and inherited to the next population.

Step 4-3: Application of crossover operator
The crossover operator is applied to the individuals, in order to create new individuals. Based on the rank, two individuals are selected by using the roulette selection. Two crossover points are randomly selected in the individuals. If the gene between the crossover points in an individual has more than one evaluation value of 1, the position of gene is changed with the one of gene whose job name is same as the job name of the allele in the other individual. The rest of genes are inherited to offspring individuals in the next population.

Step 4-4: Application of mutation operator
The mutation operator inverts the positions of genes between two points selected randomly in the individual.

Step 5: Evaluation of modified production schedule

Step 5-1: Selection of most suitable production schedule
The most suitable production schedule is selected in the new individuals created in Step 4, in order to exchange it for the current production schedule. The value of each objective function is firstly normalized by using the following equation. This equation makes it lie between 0 and 1.

$$Of'_p = \frac{Of_p - \min Of_p}{\max Of_p - \min Of_p} \quad (7)$$

Where,
Of'_p : normalized value of the objective function f_p.
Of_p : value of the objective function f_p.
$\min Of_p$: minimum value of the objective function f_p.
$\max Of_p$: maximum value of the objective function f_p.

All the normalized objective functions are secondly combined as an integrated objective function by using the following equation. Each individual is provided with an integrated objective function as a criterion for the selection of the most suitable production schedule in the new individuals.

$$OF = \sum_{p=1}^{r} w_p Of'_p \quad (8)$$

$$\sum_{p=1}^{r} w_p = 1 \quad (9)$$

Where,
w_p : weight for the objective function f_p.

Step 5-2: Exchange of current production schedule
If the most suitable production schedule in the new individuals makes one of the objective functions, such as the

total tardiness and total flow time, shorter than the one of the current production schedule, the new production schedule is substituted for the current production schedule. If all the objective functions of the new production schedule are shorter than the constraint on the objective functions, the reactive scheduling process is terminated.

All the steps from Step 1 to Step 5 are repeated, until the created production schedule satisfies the given constraint on all the objective functions or all the manufacturing operations have started in the manufacturing system.

5 Computational Experiments for Multi-objective Scheduling Problems

A prototype of multi-objective reactive scheduling system has been implemented and applied to the computational experiments for job-shop type scheduling problems. The experimental results of the new reactive scheduling method with the advanced crossover method were compared with the ones of the previous reactive scheduling method with the conventional crossover method. Numbers of jobs, manufacturing equipment and operations considered in the experiments were 50, 10 and 500, respectively. Parameters of GA, such as population size, crossover rate and mutation rate, were 30, 0.8 and 0.2, respectively. These parameter values were estimated based on preliminary case studies of job-shop type production scheduling problems.

Operations were randomly selected and their processing time was enlarged to less than five times. The prototype system automatically started reactive scheduling, in order to modify the disturbed production schedule. Figures 4 and 5 show experimental results of the previous reactive scheduling method and the new reactive scheduling method. The horizontal axis shows the time for reactive scheduling process and manufacturing process. The vertical axis shows the total tardiness and the total flow time of the modified production schedule in Figs. 4 and 5, respectively. These figures show that the new reactive scheduling method improves the disturbed production schedule faster than the previous method from the viewpoint of the minimization of the total tardiness and the total flow time.

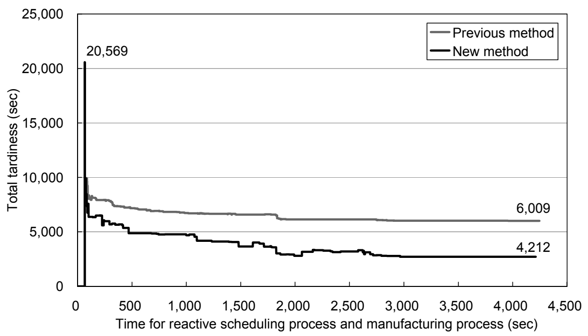

Fig. 4. Experimental results of total tardiness

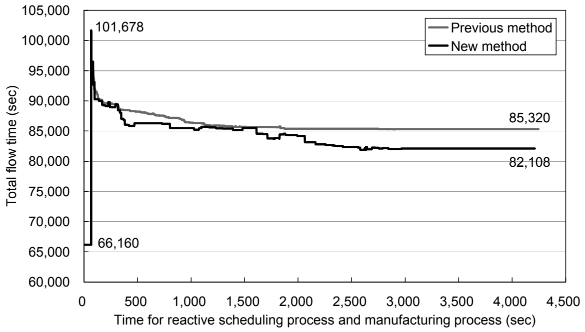

Fig. 5. Experimental results of total flow time

Ten cases of computational experiments were carried out based on the same initial production schedule. Different operations were randomly selected on each experiment and their processing time was enlarged. Figure 6 summarizes experimental results of the previous reactive scheduling method and the new reactive scheduling method. The vertical axis shows the decrease rate of the increased total tardiness and the decrease rate of the increased total flow time. This figure shows that the new reactive scheduling method improves the disturbed production schedule better than the previous method from the viewpoint of the minimization of the total tardiness and the total flow time.

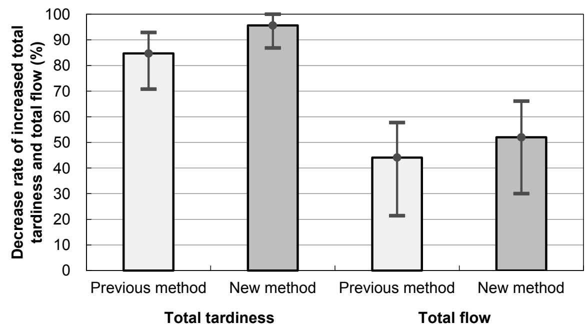

Fig. 6. Ten cases of experimental results

Figures 7 and 8 show the variations of individuals of all the populations generated in the previous reactive scheduling method and the new reactive scheduling method, respectively. The horizontal axis shows the total tardiness. The vertical axis shows the total flow time. Through the analysis of the variations of individuals, the new reactive scheduling method generates more various individuals for searching feasible production schedules than the previous reactive scheduling method.

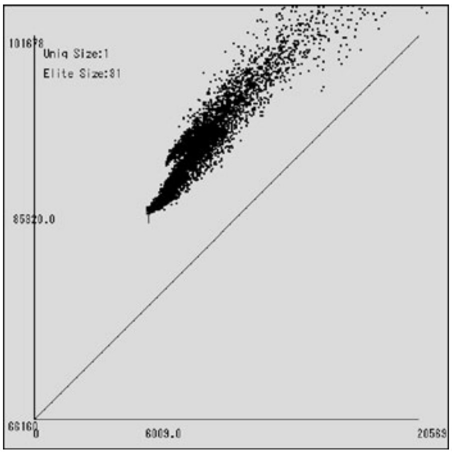

Fig. 7. Variations of individuals in previous method

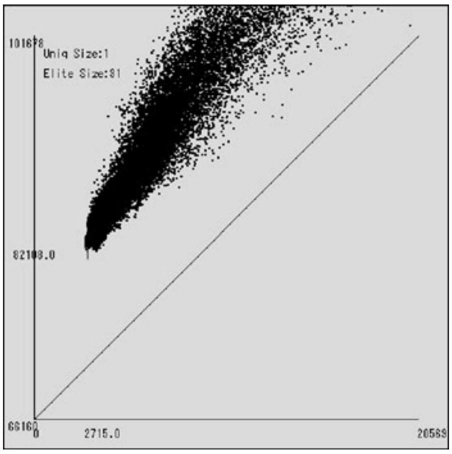

Fig. 8. Variations of individuals in new method

6 Conclusions

This paper proposed a new crossover method to improve the performance of the GA based reactive scheduling method for the total tardiness minimization problems and the total flow time minimization problems. The new crossover method exchanges genes of two individuals in consideration of the dominance and the recessiveness of genes, in order to improve the production schedule faster than the conventional method. The multi-objective reactive scheduling method was also proposed based on the improved reactive scheduling method in this research. The combination of the evaluation value for recessiveness of genes was discussed for the multi-objective reactive scheduling problems of the total tardiness minimization and the total flow time minimization. A prototype of multi-objective reactive scheduling system was developed and applied to the multi-objective reactive scheduling problems for the total tardiness minimization and the total flow time minimization. The experimental results have shown that the new reactive scheduling method is superior to the previous reactive scheduling method from the viewpoint of the minimization of the total tardiness and the total flow time.

7 References

[1] Shin H, Kuroda M, (1996) An autonomous job shop scheduling system under dynamic production environment considering machine breakdowns. Advances in production management systems, Chapman & Hall: 399-410

[2] Sugimura N, Tanimizu Y, Iwamura K, (2004) A study on real-time scheduling for holonic manufacturing system. CIRP journal of manufacturing systems, 33, 5: 467-475

[3] Smith SF, (1995) Reactive scheduling systems. Intelligent scheduling systems, Kluwer academic: 155-192

[4] Tanimizu Y, Sugimura N, (2002) A study on reactive scheduling based on genetic algorithm. Proc. of the 35th CIRP international seminar on manufacturing systems: 219-224

[5] Hollanad JH, (1975) Adaptation in natural and artificial systems. University of Michigan press

[6] Goldberg DE, (1989) Genetic algorithm in search, optimization and machine learning. Addison Wesley, Reading, Massachusetts