Genetic algorithm approach to multi-objective scheduling problem in plastics forming plant

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Abstract

In this paper, a method of applying genetic algorithms (GAs) to multi-objective scheduling problems is proposed. The key points are (1) an alphabetical representation (i.e., genotype) of feasible schedules (i.e., phenotype), and (2) a reproduction operator of GAs which combines the parallel selection with the Pareto reservation strategy. In the paper, through computational experiments, it is shown that not only one of the Pareto-optimal schedules of a problem but a set of such solutions can be obtained by a single run of the proposed method.

Keywords

Production scheduling, Multi-objective optimization, Plastics forming plant, Genetic algorithm, Pareto-optimal solution.

1. INTRODUCTION

This paper deals with a multi-objective scheduling problem in plastics forming plant. This problem basically belongs to the class of unrelated parallel machine problems, but includes multiple performance indexes (i.e., objective functions) as well as several restrictions which originate from the necessity to

Advances in Production Management Systems N. Okino, H. Tamura & S. Fujii (Eds.)

use auxiliary equipments such as "dies." Thus, it can be regarded as a representative example of "complex" scheduling problems arising in industries. Motivation of research is to establish a computer technique which can replace or support experienced engineers who are actually making daily schedules for the plant.

As for solution of practical scheduling problems in general, most of methods proposed in the past researches use some sort of dispatching rules, and researchers' efforts have been concentrated upon clarifying "which rules fit which problems." We have presented a new scope for the study of the practical scheduling problems by proposing a method to solve them without relying upon dispatching rules (Tamaki *et al.*, 1993; Tamaki *et al.*, 1995a). Namely, the scheduling problems in the plastics forming plant, where we consider a weighted sum of multiple performance indexes as a single-objective function, are transformed into the mathematical programming problem, and feasible schedules are represented by strings. This formulation enables us to use the meta-heuristics (Reeves, 1993) such as simulated annealing and genetic algorithms (Goldberg, 1989), which are known to be effective for other sorts of combinatorial optimization problems.

In this paper, we deal with the multiple objective functions as they are, and extend the way of applying genetic algorithms to the single-objective problems by using the reproduction operator proposed so far (Tamaki *et al.*, 1995b). This approach enables us to generate not only one of the Pareto optimal schedules (i.e., non-dominated schedules) of the problem but a set of such schedules. Through computational experiments, we show the effectiveness of the proposed approach is shown.

2. SCHEDULING PROBLEM IN PLASTICS FORMING PLANT

Several kinds of pipes are produced in the plastics forming plant. There exist several forming machines and several dies. A "lot" of pipes (of a kind) are produced by using a machine equipped with a die. The type of die (we call "die-type") determines the kind of production (i.e., diameter and thickness of pipes), and the combination of the machine and the die-type determines production speed. In Fig. 1, the case of 4 machines and 4 die-types is pictured in order to give a global idea of the problem, whereas our practical plant have more (e.g., $10 \sim 20$) machines and die-types.

The total number of lots (we call "jobs") to be produced in a pre-assigned period is prescribed together with the type of production and the quantities of pipes of each lot. Here, the scheduling problem is defined to find a schedule (i.e., the assignment of jobs to machines and the processing order of jobs on each machine) which minimize several objective functions (e.g., the maximum completion time, the maximum tardiness, the total idle time, etc.).

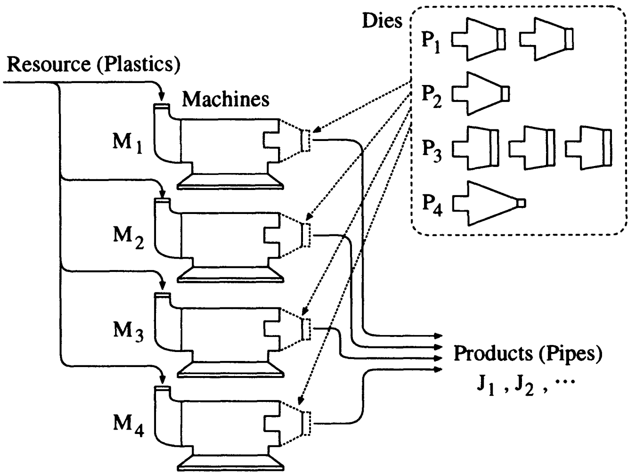


Figure 1 Plastics forming plant with 4 machines and 4 die-types. The symbol 'M', 'P', 'J' represent a machine, a die-type and a job, respectively.

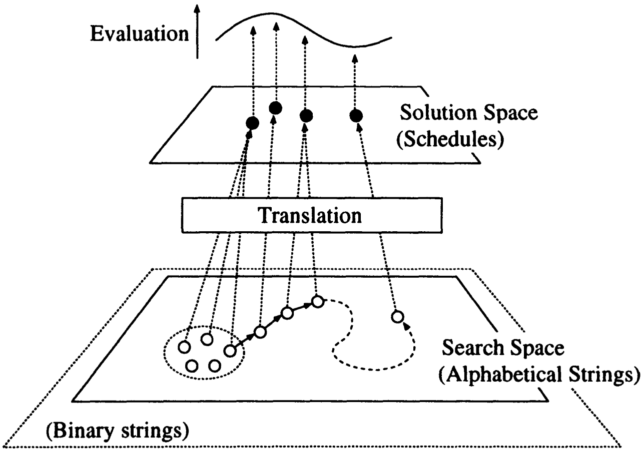
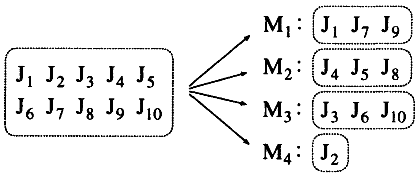
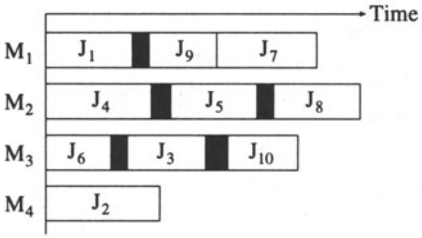


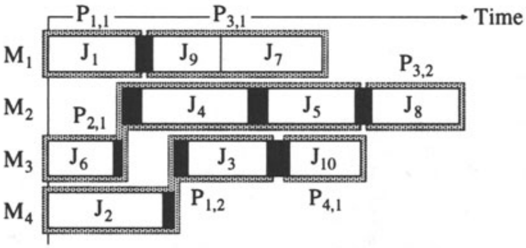
Figure 2 Search space and solution space. The translation part produces a feasible schedule from an arbitrarily given alphabetical string.



(a) Determining the machine for each job — $\{\alpha_j\}$



(b) Determining the sequence of jobs on each machine — $\{\beta_j\}$



(c) Determining the sequence of jobs which uses the same die — $\{\gamma_j\}$

Figure 3 Outline of the procedure to translate an alphabetical string into a schedule. A set-up time is indicated by a black rectangle.

3. GENETIC ALGORITHM APPROACH

In order to apply the meta-heuristics such as genetic algorithms (GAs) to the problem, it is required that feasible schedules are represented symbolically (e.g., as binary strings). The simple way to represent a schedule S by a binary string B is to use the linear array obtained by lining up the 0-1 variables of the IP problem in a certain order (Tamaki *et al.*, 1993). This method seems not to include any problem when we only look at the process of determining B from S. However, if we look at the reverse process, we immediately face with the problem that almost all strings correspond to infeasible schedules. This

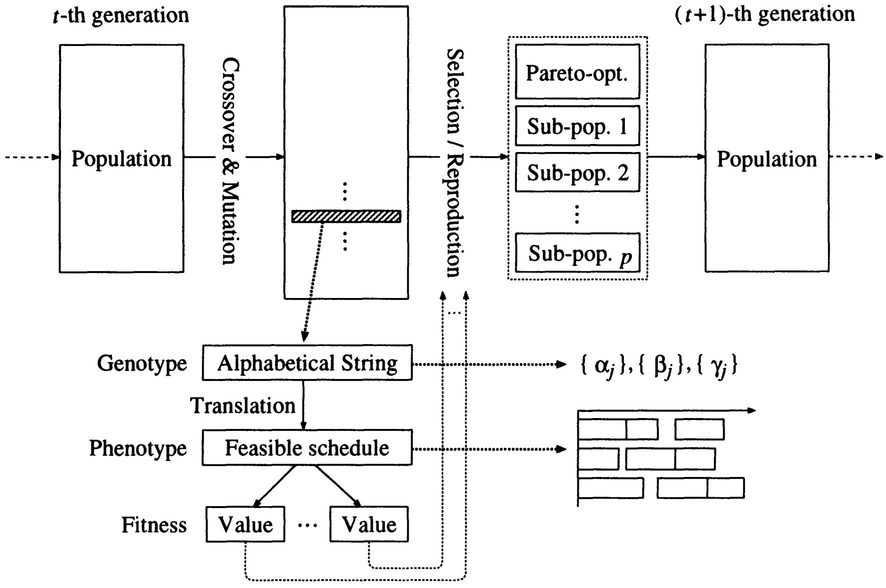


Figure 4 Outline of the genetic algorithm approach to the multi-objective scheduling problem.

problem causes serious inefficiencies in the application of the meta-heuristics that the search can be proceeded by one step only after an extremely large repetition of producing new strings. So, we have proposed a method to produce a feasible schedule from an arbitrarily given binary string of a sufficient length (Tamaki *et al.*, 1993). Moreover, we have proposed a way of improving a search by adopting an alphabetical representation (Tamaki *et al.*, 1995a). That is, a schedule is represented by an alphabetical string $A = (\alpha, \beta, \gamma)$, where

α_j : the index of machine to which J_j is assigned,

β_j : the priority used to fix both the order of jobs on each machine and the order of jobs using each die,

γ_j : the index of die used for processing J_j [1].

Using this representation, the actual search space by the meta-heuristics is reduced as compared with the case of using the binary representation (Fig. 2), and then, the efficiency of search can be much more improved. In Fig. 3, the

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[1] Every die of the same type are to be distinguished (i.e., the ℓ-th die of type k is represented by $P_{k\ell}$).

outline of translating an alphabetical string into a schedule is shown schematically.

In the case of considering multiple objective functions, it is necessary that the operations (especially, the reproduction operation) of the conventional GAs should be extended in order to generate not a single solution but various solutions in the Pareto optimal set. So far, several ways of designing the reproduction operator have been proposed for multi-objective function optimization problems (Fonseca and Fleming, 1995; Tamaki *et al.*, 1996), In this paper, we adopt the Pareto reservation strategy (Tamaki *et al.*, 1996):

(a) Non-dominated individuals (i.e., schedules) in a population at each generation are all reserved in the next generation.

(b) If the number of non-dominated individuals are less than the population size, the rest of the population in the next generation are filled by adopting the parallel selection method, i.e., the selection/reproduction is performed in parallel according to each objective function.

(c) Oppositely, if the number of such individuals exceeds the population size, individuals in the next generation are selected among the non-dominated individuals by applying a fitness sharing technique.

In Fig. 4, the outline of our GA approach to the multi-objective scheduling problems in the plastics forming plant is shown.

4. COMPUTATIONAL EXAMPLES

An example of the multi-objective scheduling problem in the plastics forming plant with 40 jobs, 10 machines and 13 die-types have been solved, where

(a) I_{sum} : the sum of the idle time of every machines,

(b) $T_{\max}$: the maximum tardiness of jobs, and

(c) $C_{\max}$: the maximum completion time of jobs (i.e., a makespan)

are considered as the objective functions. In applying GAs, the alphabetical representation of schedules are adopted, and the following three kinds of genetic operators are implemented:

(a) Pareto reservation strategy with parallel selection (described in **3.**),

(b) Uniform crossover, and

(c) One-alphabet-exchange mutation.

Table 1 Setting of GA parameters

Population size :	200
Number of Generations :	300
Crossover Rate :	0.6
Mutation Rate :	0.015 / string

The setting of GA parameters is shown in Table 1.

In Fig. 5, the objective function values of obtained schedules in the 20th, the 100th and the final (i.e., 300th) generations are shown. We can observe, from Fig. 5, that a variety of the Pareto-optimal schedules have been obtained by the proposed approach.

5. CONCLUSION

In this paper, a method of applying genetic algorithms (GAs) to multi-objective scheduling problems in plastics forming plant is proposed, with respect mainly to selection/reproduction operation which are essential for generating a variety of Pareto-optimal schedules. Through several examples of practical size, the usefulness of the proposed method is confirmed.

In general, in multi-objective optimization by GAs, however, it is important to make the crossover operator efficient. If the population is distributed widely near the Pareto-optimal set, crossover operation with random paring may not yield good search points.

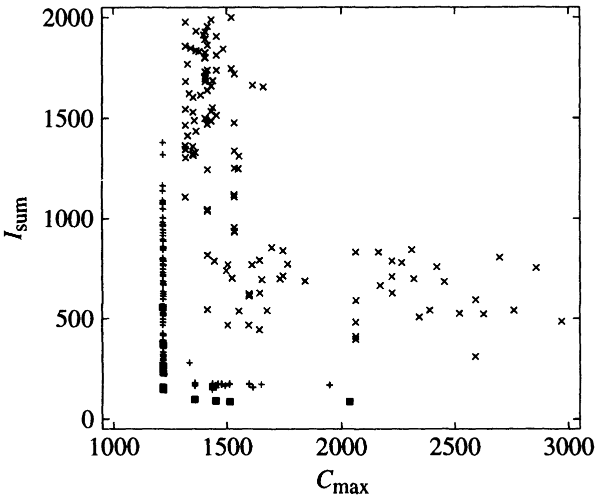
Further, for the multi-objective scheduling, to obtain the Pareto-optimal set is not its goal but the first step of the goal. It is needed, for example, to build a decision support system based on the approach shown in this paper.

Finally, this research was supported by the Grant-in-Aid for Scientific Research on the Priority Area "System Theory of Function Emergence" from the Ministry of Education, Science, Sports and Culture of Japan.

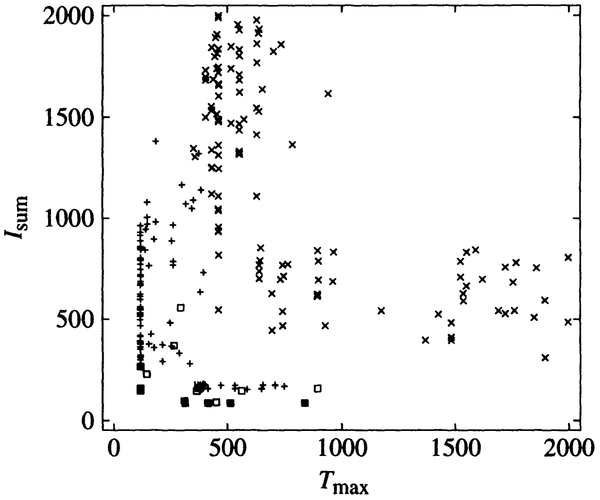
6. REFERENCES

Fonseca, C. M. and Fleming, P. J. (1995), An overview of evolutionary algorithms in multiobjective optimization, *Evolutionary Computation,* **3** (1), pp. 1–16, MIT press.

Goldberg, D. E. (1989), *Genetic Algorithms in Search, Optimization and Machine Learning,* Addison-Wesley.



(a) $C_{\max} - I_{\mathrm{sum}}$



(b) $T_{\max} - I_{\mathrm{sum}}$

Figure 5 Results of computational experiments. The symbols ×, +, and □ indicate the schedule at the 20th, the 100th, and the final generations, respectively. Moreover, the symbol ■ indicates the Pareto-optimal schedule at the final generation.

Reeves, C. R. (1993), *Modern Heuristic Techniques for Combinatorial Problems,* Blackwell Scientific.

Tamaki, H., Hasegawa, Y., Kozasa, J. and Araki, M. (1993), Scheduling in Plastics Forming Plant: A Binary Representation Approach, *Proc. of the 32nd IEEE Conf. on Decision and Control,* pp. 3845–3850.

Tamaki, H., Taguchi, K. and Araki, M. (1995a), Application of Meta-Heuristics to Scheduling Problems in Plastics Forming Plant, *Proc. of the 7th IFAC/IFORS/IMACS Symp. on Large Scale Systems,* pp. 409–414.

Tamaki, H., Mori, M., and Araki, M. (1995b), Generation of a Set of Pareto-Optimal Solutions by Genetic Algorithms, *Trans. of the Society of Instrument and Control,* **31** (8), pp. 1185–1192 (in Japanese).

Tamaki, H., Kita, H. and Kobayashi, S. (1996), Multi-Objective Optimization by Genetic Algorithms: A Review, *Proc. of the 1996 IEEE Int. Conf. on Evolutionary Computation,* pp. 517–522.

7. BIOGRAPHY

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