GA-Based Precast Production Planning System

Chien-Ho Ko[1] and Shu-Fan Wang[2]

Abstract

Appropriate production plans can make resources utilized effectively as well as minimize waste. However, currently most of the precast fabricators propose production plans depending on the rule of thumb, resulting in the squander of resources and postponed delivery. Computerized scheduling techniques provide more precise outcomes than those made manually. The goal of this study is to develop a GA-Based Precast Production Planning System to assist production managers arranging production plans. This research first establishes a flow-shop sequencing model based on the current production status by considering the buffer sizes between production stations. Then, a multi-objective genetic algorithm is applied to search for solutions with minimum makespan and tardiness penalty. The performance of the proposed system is verified using two examples. The result of which demonstrates that the proposed system can offer appropriate production plans. Furthermore, by taking buffer sizes into consideration, more reasonable and feasible production sequences can be achieved.

Keywords: Precast, flowshop, production planning, genetic algorithms, decision support systems, buffers.

Introduction

The formwork method has been applied in building construction for a long period of time. However, such a traditional construction method can be hardly competitive as the cost of labor and notion of time efficiency rise each year. Precast construction is an enhancement method accomplished by erecting prefabricated concrete elements (Bennett 2005). To support a construction schedule, precast fabricators deliver elements to a site according to its erection schedule. To enhance the competitiveness of a fabricator, production planers face the challenges of satisfying multiple objectives since one may conflict with the others (Chan and Hu 2002). Due to the development in technology and the mutation in the manufacturing industry, traditional simple scheduling cannot be capable of dealing with the current complex production systems.

Leu and Hwang (2001) regarded the three working zones in a precast factory as a flow-shop sequencing model. A genetic algorithm was applied to achieve the solution for this model with minimum makespan. In another research (Leu and Hwang 2002) written by the same authors, a genetic algorithm was tested in several projects for minimizing the time spent on producing precast elements. However, precast fabrication requires a rather large space while manufacturing, previous studies have ignored buffer size between working stations, thereby may result in unrealistic production plans. The objective of this study is to develop a GA-Based Precast Production Planning System to assist production managers

[1] Professor, Department of Civil Engineering, National Pingtung University of Science and Technology, 1, Shuefu Road, Neipu, Pingtung 91201, Taiwan, Tel: +886-8-7703202, Fax: +886-8-7740122, E-mail: ko@mail.npust.edu.tw

[2] MS, Department of Industrial Engineering and Technology Management, Da-Yeh University, 168, University Rd., Dacun, Changhua 51591, Taiwan

making appropriate production plans. A limited buffer size between stations is considered in the system.

Precast Production Practice

This section explains current practice of precast production. In the process of construction, precast elements are made by a process which can be highly customized. There are two phases within this process, namely the design and the fabricating. In the design phase, designers will translate customers' demands into physical shop drawings before the precast elements are fabricated. Communications and negotiations are necessary to ensure that clients' needs have been fulfilled. After confirmed by the clients, the drawings will be used in the second phase in the production of precast elements. The focus of this study is on the fabricating phase, which is conducted after the design phase but before the hoisting construction on building sites.

Elements are fabricated by using various types of steel molds depending on different designs in precast factories. The way how the precast industry uses steel molds is identical to other manufacturing industries. In general, production systems of the manufacturing industry can be roughly divided into two types of method based on different layouts of the plants. One is the comprehensive method, and the other is the specialized method (Warszawski 1990).

With regard to the comprehensive method, all procedures of manufacturing works are conducted by the same team at the same place. After finishing all the procedures for one element, the team will move on to another station to work on the next work piece. The merit of such kind of production is that work flow can be understood easily by the crew. However, resources are not used efficiently and not easily shared among different stations. If the flow path and processing time are similar between each precast element, it will lead to the problem of requiring the same resources at the same time. The layout of this method is sketched in Figure 1.

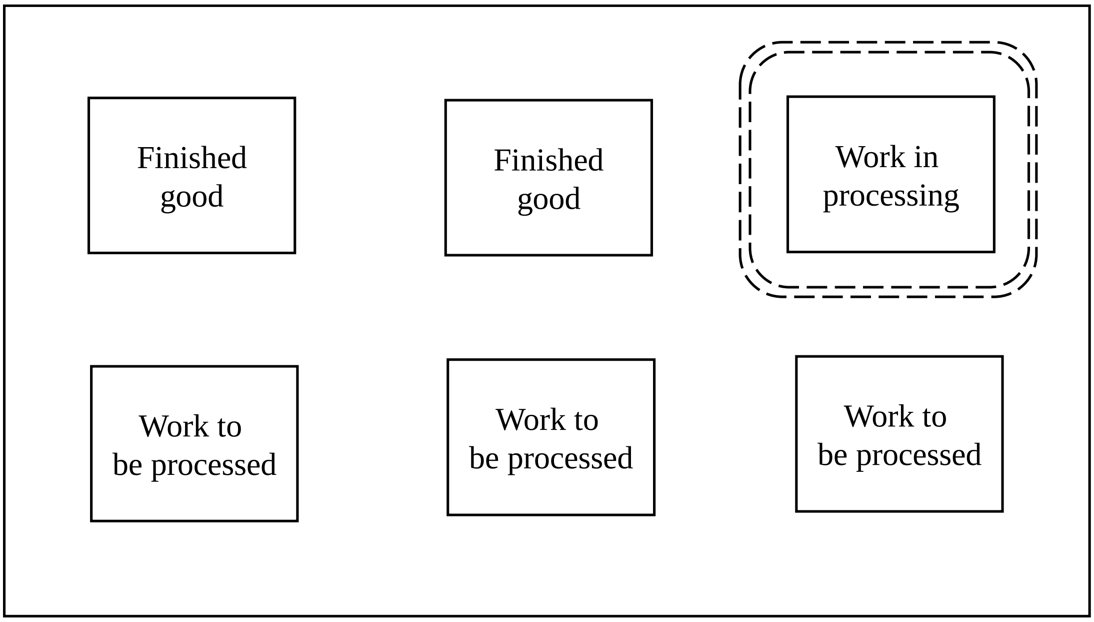

Figure 1. Comprehensive Production Method

Precast Production Modeling

Precast production can be divided into six steps: (1) mold assembly, (2) placement of reinforcement and embedded parts, (3) concrete casting, (4) curing, (5) mold stripping, and (6) product finishing. This process is depicted in Figure 2. In general, fabricators use steel molds for the purpose of reuse. A precast component generally is composed of concrete and steel bars. Reinforcements and embedded parts are placed in their positions after the mold is formed. The concrete is cast when the embedded parts are in their positions. To enhance the chemistry-solidifying concrete, steam curing is implemented; otherwise, the component concrete requires weeks to reach its legal strength. The molds can be stripped after the concrete solidifies. Due to the cost of developing steel molds, fabricators reuse them once they are stripped. The final step in production is finishing. Minor defects such as scratches, peel-offs, and uneven surfaces are treated in this step.

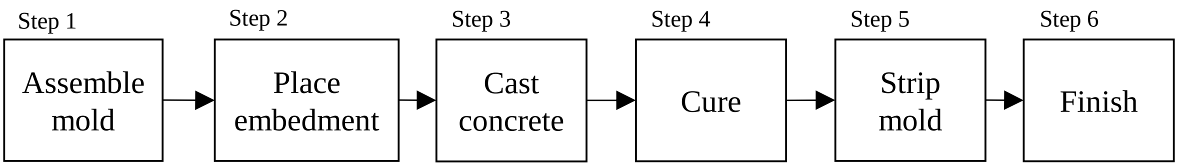

Figure 2. Precast production process

The traditional flowshop sequencing problem regards production as a continuous flow. The typical equation used to calculate the completion time is shown in Eq. (1):

$$C\left(J_j, M_k\right) = Max\left\{C(J_{j-1}, M_k), C(J_j, M_{k-1})\right\} + P_{jk} \quad (1)$$

where $C\left(J_j, M_k\right)$ denotes the completion time for the jth element in k station and P_{jk} is an operation time for that element ($P_{jk} \geq 0$).

Production Planning System

Searching Engine

The Multi-Objective Genetic Algorithm (MOGA) has been extensively adopted in numerous multi-objective decision-making analyses. MOGA, obviously, has turned into one of the most eminent solutions for multi-objective scheduling (Montoya et al. 2014). This research proposes a multi-objective genetic algorithm to search for appropriate production plans. The algorithm is adopted from the Multi-Objective Genetic Local Search (MOGLS) proposed by Ishibuchi and Murata (Ishibuchi and Murata 1998). The evolutionary process of the developed algorithm is shown in Figure 3. Each step is explained as below.

- Encoding

The factors affecting production makespan include both the resources and the sequence of production. Certain resources such as the number of cranes and the size of the factory cannot be changed by the production planers. Others such as buffer size between stations, number of molds, and working hours can be determined.

- Initializing population

To provide an equal opportunity for every state space, a set of initial solutions is randomly generated.

- Calculating objective function

The goal of the study is to simultaneously minimize cost and production duration. Scheduling performance is therefore evaluated by its makespan and penalty costs (Ko 2013).

- Updating Pareto solution

To be sure that the derived solutions conform to Pareto's definition, every generation should be updated to this solution pool. Chromosomes in the pool which dissatisfy Pareto's definition are removed.

- Enhancing by elitism

Elitism has been proven successful in enhancing GA searches (Ko and Wang 2010), surviving a certain number of Pareto solutions to the next generation. By applying this strategy, the fitness increases from one generation to the next.

- Selecting

A selection operator is used to choose chromosomes according to their fitness. A chromosome with a higher fitness value has a greater chance for survival.

- Crossing over

A GA extends the searching space by a crossover operator, which produces the next generation by exchanging partial information from the parents. A position-based two-cut-point crossover is used in this study.

- Mutating

The mutation operator produces spontaneous random changes in various chromosomes and protects against premature loss of important notations. This study uses shift mutation that randomly selects two points.

- Searching local area

This study searches the local area by using a mutation operator. If the solution obtained through the local search is better than the current solution, the algorithm mutates population again.

- Replacing

In this process, the previous population is renewed by the generated offspring. The next generation can continuously include new solutions for evolution.

- Terminating conditions

The terminate conditions provide the criterion for stopping the evolutionary process, which is terminated by iterations in this study.

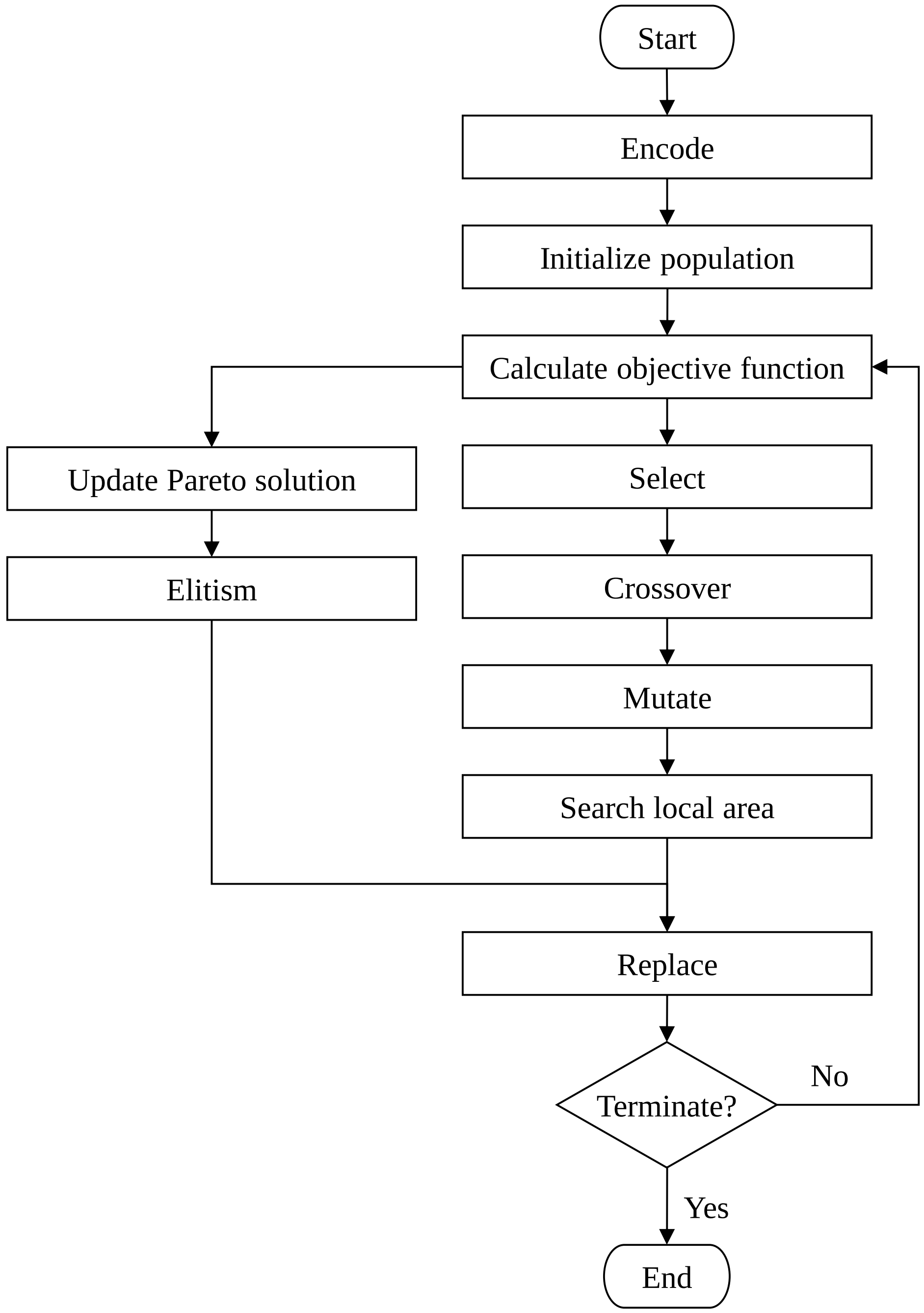

Figure 3. Evolutionary Process of Multi-Objective Genetic Algorithm

System Development

A production planning system is developed for managers in precast factories to use the scheduling method proposed in this study. Through graphical user interfaces programmed using JAVA language, users can easily acquire necessary production information. Search engine is programmed using C language for increasing computing efficiency. Two system modules are explained as follows.

Objectives Settings

In addition to the default objectives (i.e. makespan and total penalty cost), this module provides other evaluation criteria, namely idle time, total flow time, and maximum tardiness. This module is shown in Figure 4.

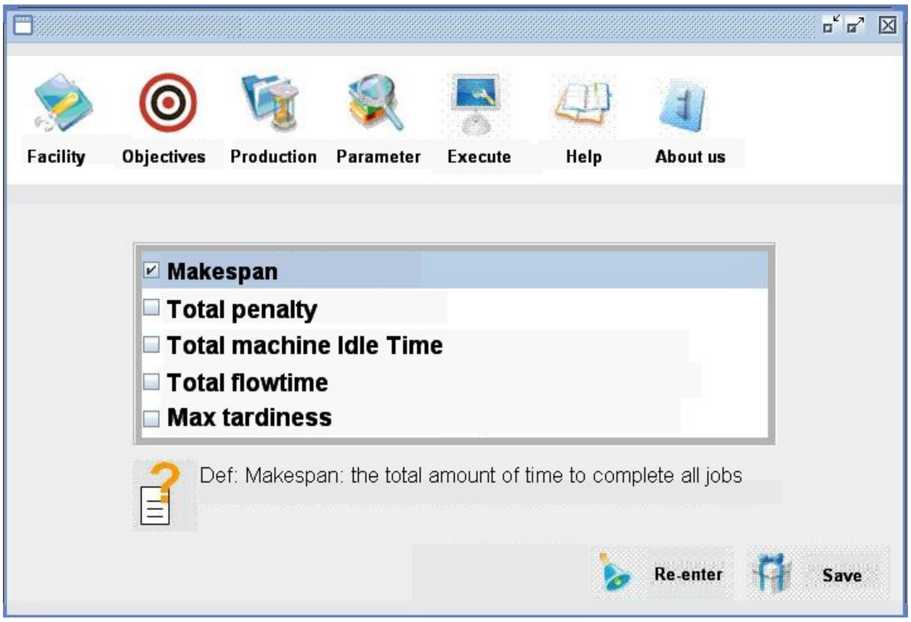

Figure 4. Objectives Configuration Form

Production Information Input

This module contains two parts. The first encompasses the setting of the number of precast elements and the required mold types. The second includes the inputs of mold types for precast elements, production time, due date, and penalty cost. This module is shown in Figure 5.

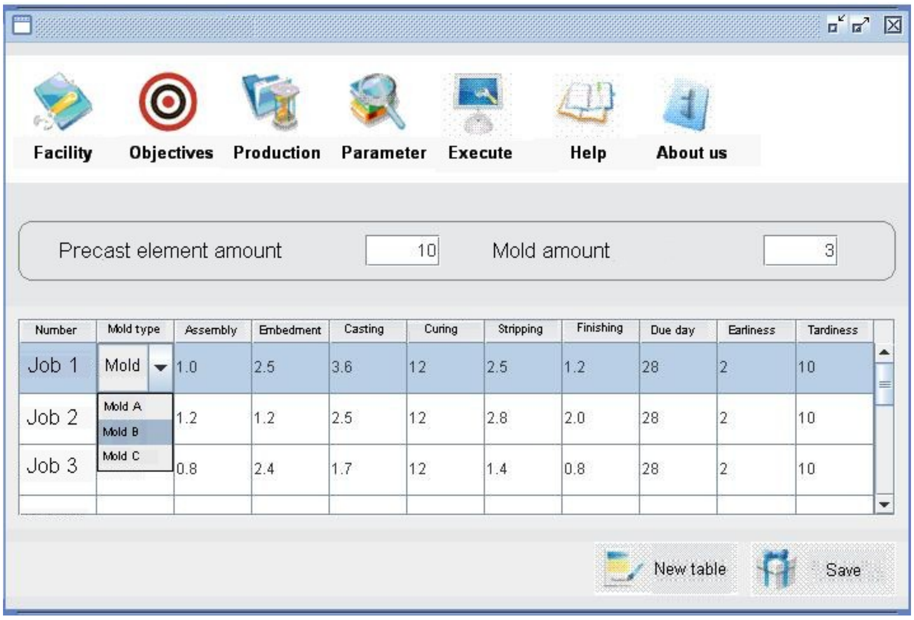

Figure 5. Production Information Form

Experiment

Previous researches related to the production planning usually assume that buffer sizes between stations were infinite. Nevertheless, precast elements require a lot of space. Production plans might be unrealistic if the real buffer sizes are not taken into account. This study deals with the impact of buffer sizes on production planning. Ten elements are experimented. Production data, as shown in Table 1, were adopted from Benjaoran et al. (2005). Transportation time is included in the makespan. Related parameter settings are as followed: The population size is 20, crossover rate is 0.9, and mutation rate is 0.005. The evolution over 200 generations is executed in the experiments. The results are demonstrated in Table 2.

In Table 2 the provided buffer size is the greatest capacity in the production system. The maximum buffer size required in the system is two. When the buffer size is larger than two, it has nearly no influence on the makespan (i.e. 126.9) and total penalty cost (i.e. 701.6). The unneeded buffer size not only occupies space, but in practice may increase transportation time and cost that could be referred as waste. However, if the buffer size is smaller than the required buffer size, the makespan and total penalty cost increase responsively. Since only few elements are produced in this experiment, the impact is not obvious.

Table 1. Production Data

Element No.	Steel mold type	Manufacturing time					Due day (h)	Penalty costs	
		Mold assembly	Embedded parts placement	Concrete casting	Mold stripping	Finishing		Inventory	Tardiness
1	A	2	1.6	2.4	2.5	1	112	2	10
2	B	3.4	4	4.0	2.4	5	112	2	10
3	A	0.8	1	1.2	0.8	0	112	1	10
4	A	0.6	0.8	1.0	0.6	2	112	1	10
5	C	3	3.6	2.4	2.4	3	208	2	10
6	A	3	3.2	3.0	3	1.6	128	2	10
7	C	1.3	0.9	2.4	1.9	1.8	144	2	10
8	B	1.7	1.4	1.1	0.9	0.7	144	2	20
9	A	2.2	1.8	1.2	2.3	0.7	144	1	20
10	C	1.6	3.2	2.3	2.1	2.7	240	1	20

Table 2. Buffer size experimental results (for 10 jobs)

Provide buffer size	Makespan	Total penalty costs	Required buffer size
6	126.9	701.6	2
5	126.9	701.6	2
4	126.9	701.6	2
3	127.1	706.2	2
2	132.3	717.9	2
1	134.7	729.1	1

Conclusions

This study established production models based on the practical production status in precast factories. The multi-objective genetic local search algorithm is applied to search for production plans with minimum makespan and tardiness penalty. At the end, a production planning system with graphical user interfaces has been developed using JAVA and C languages. By applying suitable algorithms in which real situations are concerned, a set of Pareto-optimal solutions can be provided for production managers as the reference when creating production plans.

Two examples are applied to validate the performance of the developed system. Experimental results demonstrate that the multi-objective genetic local search algorithm developed in this study is efficient in offering solutions to complex production planning problems. In addition, considering buffer size between stations is crucial for production planning. The two outcomes mentioned above indicate that the proposed production system is capable of offering feasible solutions to precast production for enhancing decision making.

Acknowledgements

This research was funded by grant numbers NSC 95-2221-E-212-051 and NSC 96-2221-E-212-020 from the Ministry of Science and Technology, Taiwan, whose support is gratefully acknowledged. Any opinions, findings, conclusions, or recommendations expressed in this report are those of the authors and do not reflect the views of the Ministry of Science and Technology.

References

Benjaoran, V., Dawood, N. and Hobbs, B. 2005. Flowshop scheduling model for bespoke precast concrete production planning. *Journal of Construction Management and Economics*, 23, 93-105.

Bennett, D. 2005. *The Art of Precast Concrete: Colour, Texture, Expression*. Birkhäuser Basel.

Chan, W.T. and Hu, H. 2002. Constraint programming approach to precast production scheduling. *Journal of Construction Engineering and Management*, 128, 513-521.

Ko, C. H. and Wang, S. F. (2010). GA-based decision support systems for precast production planning. *Automation in Construction*, 19(7), 907-916.

Ko, C.H. (2013). Material Transshipment for Precast Fabrication. *Journal of Civil Engineering and Management*, 19(3), 335-347.

Ishibuchi, H. and Murata, H. 1998. Multi-objective genetic local search algorithm and its applications to flowshop scheduling. *IEEE Transactions on SMC*, 28, 392-403.

Leu, S.S. and Hwang, S.T. 2001. Optimal repetitive scheduling model with shareable resource constraint. *Journal of Construction Engineering and Management*, 127, 270-280.

Leu, S.S. and Hwang, S.T. 2002. GA-based resource-constrained flow-shop scheduling model for mixed precast production. *Automation in Construction*, 11, 439-452.

Montoya, F. G., Manzano-Agugliaro, F., Lopez-Marquez, S. (2014). Wind turbine selection for wind farm layout using multi-objective evolutionary algorithms. *Expert Systems with Applications*, 41(15), 6585-6595.

Warszawski, A. 1990. *Industrialization and robotics in building: a managerial approach*. New York: Harper & Row.