ARRANGING WEEKLY WORK PLANS IN CONCRETE ELEMENT PREFABRICATION USING GENETIC ALGORITHMS

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

ABSTRACT

Applying lean production concepts to precast fabrication have been proven promising. However, foreman encounters difficulties in arranging weekly work plans. The objective of this research is to overcome the difficulty when arranging weekly work plans in concrete element prefabrication.

Current practices in arranging weekly work plans are fairly basic, and depending heavily on experience, thereby resulting in inefficient resource utilization and even late delivery. To enhance weekly work planning, this research develops a flowshop sequencing model. In the model, production constraints and buffer sizes between stations are considered. A multi-objective genetic algorithm is then used to search for optimum solutions with minimum makespan and tardiness penalties. The performance of the proposed method is validated by using two case studies. The experimental results show that the research work can be used to enhance weekly work planning especially for numerous combinations of sequences.

KEY WORDS

precast fabrication, weekly work plan, genetic algorithms, flowshop sequencing model, buffer

INTRODUCTION

Precast construction is an enhancement method accomplished by prefabricated concrete elements. Precast fabricators deliver elements to a construction site according to its erection schedule. Enhancing structures by using precast elements can reduce uncertainty than casting at the construction site. In addition, precasting conforms with the needs of industrial process. As a result, precast fabrication in the construction industry can be categorized as manufacturing. Weekly work plan is one of the most important tasks when applying lean concepts in precast concrete fabrication. Different plans can induce different throughput. Engineers therefore endeavor to finish products with a minimum makespan. A makespan is defined as the total amount of time to process a fixed number of jobs. To enhance competitiveness, foremen face the challenge to satisfy multiple objectives since one objective may conflict with the others.

Current practice of making weekly work plan depends on foremen's experience. However, manually

1 Assistant Professor, Department of Civil Engineering, National Pingtung University of Science and Technology, 1, Shuefu Rd., Neipu, Pingtung 912, Taiwan, e-mail: fpecount@yahoo.com.tw, phone: +886-8-7703202, fax: +886-8-7740122; Research Director, Taiwan Lean Construction Institute; Executive Director, Lean Construction Institute Asia

2 Assistant Researcher, Taiwan Lean Construction Institute

arranging plans frequently results late delivery and wastes production resources (Dawood 1993, Chan and Hu 2002). Johnson's rule is one of the earliest and simplest methods to solve flowshop problem (Baker 1974, Baker and Scudder 1990). Flowshop is generally described as follows: there are m machines and n jobs, each job consists of m operations, and each operation requires a different machine. The n jobs have to be processed in the same sequence of m machines. However, Johnson's rule is difficult to apply to complex sequencing problems. To overcome the difficulty, heuristic methods are adopted. Chan and Hu (2002) developed a production model based on flowshop production. A Genetic Algorithm (GA) was used to solve the model. In their research, production activities were categorized into interruptible and uninterrupted groups. Benjaoran et al. (2005) proposed a flowshop sequencing model by using a multi-objective GA. Multiple objectives in their study include minimum machine idle time, minimum late delivery penalty, and minimum makespan. Penalty is a financial punishment for late delivery. Previous studies have proven that precast production is a flowshop production. Moreover, production resources have a crucial impact on throughput.

The objective of this study is to overcome the difficulties in arranging weekly work plans. To achieve the goal, precast production process is modelled. By considering the prefabricator's objectives, a multi-objective GA is used to solve the model. The paper first reviews previous works in applying lean concepts to precast fabrication. Process of precast production is explained. The multi-objective GA used to solve the problem is then addressed. The performance of multi-objective GA is discussed by experiments. Finally, conclusions induced from the experiments are documented.

REVIEW ON LEAN PRECAST PRODUCTION SYSTEMS

The promising of applying lean concepts to precast concrete fabrication has been studied by Ballard et al. (2002) and Ballard et al. (2003). In previous investigations, the researchers confirmed the applicability of lean concepts and techniques to fabrication management. A make ready process was addressed in their papers and was transited to manufacturing occurred through the workable backlog of ready work. Figure 1 shows the schematic process of applying lean concepts to precast concrete fabrication.

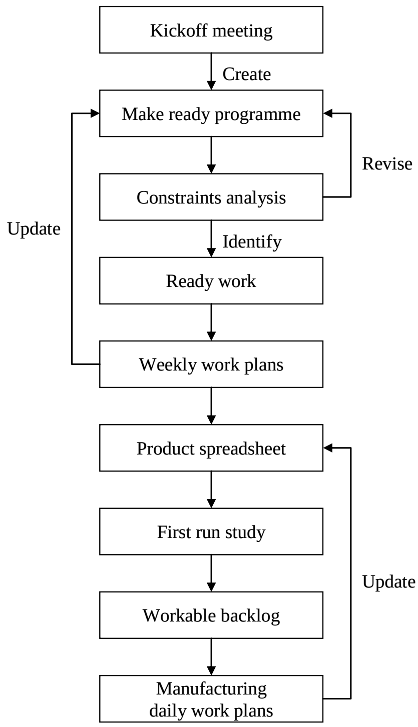

Figure 1: Process of Applying Lean Concepts ton Precast Concrete Fabrication (Ballard et al. 2002)

In the figure, while making weekly work plans, numerous combinations of sequences increase the difficulties in this activity. A set of relatively efficient solutions is required for the situation. Thus, further activities such as constraint analysis can be smoothly performed.

PRECAST PRODUCTION PROCESS

Precast production, categorized as a flowshop production, can be divided into 6 steps i.e. (1) mould assembly, (2) placement of reinforcement and all embedded parts, (3) concrete casting, (4) curing, (5) mould stripping, and (6) product finishing. The mould assembly provides a specific dimension for elements. In general, fabricators use steel moulds for a purpose of reuse. Precast concrete primarily contains two kinds of materials i.e. concrete and steel bars. In most cases, reinforcements and embedded parts are placed in their positions after the mould is completed. Embedded parts are used to connect and fix with other elements or with the structure when the precast elements are assembled. The concrete is cast when everything inside the element is in the right place. To enhance the chemistry solidifying concrete, curing concrete with steam is implemented; otherwise, concrete takes weeks to reach its legal strength. Moving, erecting, or assembling elements before the legal strength is achieved may cause damage. Moulds can be striped after the concrete becomes solid. Due to the cost of developing steel moulds, fabricators reuse them once they are stripped. The final step in production is finishing. Minor defects such as scratches, peel-offs, uneven surfaces are treated in this step.

The traditional flowshop sequencing problem regarded production as a continuous flow. However, precast production includes activities that can be done after working hours. Typical equation shown in Equation (1) cannot meet the needs of precast production.

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

Notations used in Equation (1) are explained as follows:

$C(J_j, M_k)$: Completion time for jth element in k machine.

P_{jk} : Operation time for jth element in k machine, $P_{jk} \geq 0$.

Equation (1) assumes an infinite buffer size between stations. Due to the large size of precast elements, Equation (1) is reformulated as Equation (2):

$$C(J_j, M_k) = Max\{C(J_{j-1}, M_k) + WT_{j-1,k}, C(J_j, M_{k-1})\} + P_{jk} \quad (2)$$

where $WT_{j-1,k}$ is the time for (j-1)th element in k machine waiting to be sent to buffer.

The Gantt chart of precast production is illustrated in Figure 2. In the production process, interruptible activities including mould assembly, placement of parts, mould stripping, and finishing can be done by the next day. Curing is categorized as uninterruptible activity that must be done continuously until completion. It is a time-consuming task and is frequently completed by machines without workers. As a result, it can be arranged in any time, even after the hours of working day. The other special requirement for curing is that it must be done right after casting i.e. no wait.

Moulds are necessary for precast fabrication. Number of moulds is a crucial constrain for production scheduler. Due to the high cost of steel mould, fabricators only develop a few moulds. As a result, makespan and throughput are harnessed by number of moulds. For example, due to a limited number of type A mould, fabrication of element 3 with mould A cannot be begun until element 1 releases that mould. The example demonstrates a situation in which the fabrication waits for a mould, a frequent occurrence in actual practice. In the process of scheduling, sequence of moulds is arranged according to the number of moulds and types of moulds.

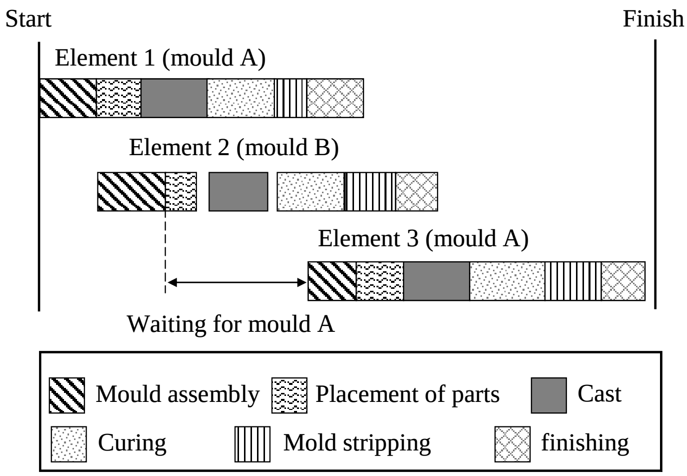

Figure 2: Gantt Chart for Precast Production

MULTI-OBJECTIVE GENETIC ALGORITHM

This study adopts the Multi-Objective Genetic Local Search Algorithm (MOGLS) proposed by Ishibuchi et al. (1998) to search for optimum work plans. The evolutionary process of MOGLS is represented in Figure 3. Each step is discussed in the following sections.

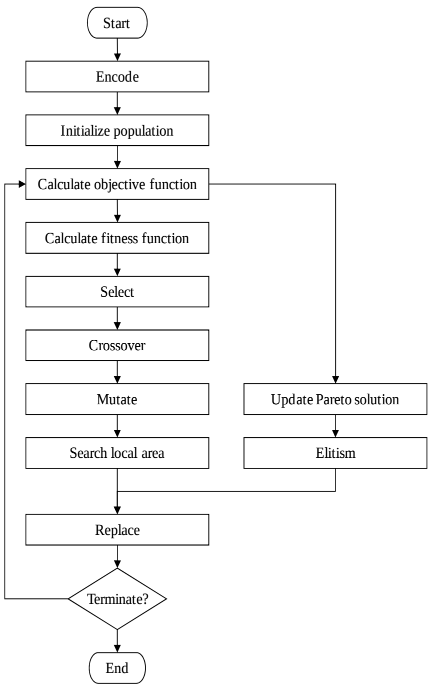

Figure 3: Evolutionary Process of MOGLS

ENCODE

The factors affecting precast makespan include both resources and sequence. Some production resources such as the number of cranes and size of the factory cannot be changed by foremen. Others such as buffer size between stations, number of moulds, and working hours can be determined by them. This study encodes work plans by job sequence. Buffer sizes and amount of moulds are treated as production constraints while scheduling.

INITIALIZE POPULATION

A variation in an initial solution with higher fitness values can improve the searching efficiency. To provide an equal opportunity for every state space, a set of initial solutions are randomly generated. The chromosomes offer a base for further evolutionary processing.

CALCULATE OBJECTIVE FUNCTION

In this step, chromosomes corresponding with precast production model are decoded. Two objectives are considered in the study: minimum makespan and minimum cost of penalty. The objective function is displayed in Equation (3)

$$f(x) = \omega_1\left(f_1(x)\right) + \omega_2\left(f_2(x)\right) \tag{3}$$

where ω_1, ω_2 are positive weights and $\omega_1 + \omega_2 = 1$. $f_1(x)$ is a makespan function and $f_2(x)$ is a penalty function.

UPDATE PARETO SOLUTION

To make sure that derived solutions conform to the definition of Pareto solution, every generation has to update Pareto solution pool. Pareto solutions are defined as nondominated solutions for which no improvement in any objective function is possible without sacrificing at least one of the other objective functions. The way to update the pool is to put the chromosomes that conform to the definition of Pareto solution in the Pareto solution pool.

CALCULATE FITNESS FUNCTION

To evaluate the fitness of each chromosome, objective value is converted to fitness value. In multi-objective programming, since distribution of each objective value is deferent, each objective value is normalized in advance. Then, a weighted-sum method can be applied. Cochran et al. (2003) proposed that sub-objectives are normalized by its fittest value. Equation (4) is thus used to convert fitness value.

$$f(x) = \omega_1\left(\frac{f_1(x)}{f_1^*(x)}\right) + \omega_2\left(\frac{f_2(x)}{f_2^*(x)}\right) \tag{4}$$

where f_1^*, f_2^* represent the minimum makespan and minimum cost of penalty in the initial solution individually.

SELECT

A selection operator is used to choose chromosomes according to their fitness. A chromosome with higher fitness value has a greater chance for survival. The purpose of this operator is to choose fitter chromosomes for evolving better generations. This study adopts a roulette-wheel method for selection (Goldberg 1989). For population size N_{pop} and elitism number N_{elite}, every generation selects $\left(N_{pop} - N_{elite}\right)$ chromosomes.

CROSSOVER

A GA extends the searching space by a crossover operator, which produces the next generation by exchanging partial information from the parents. The resulting generation represents a new solution set. This study uses a two-point crossover that randomly determines two points. The genes between the two points remain. The other parts are exchanged.

MUTATE

The mutation operator produces spontaneous random changes in various chromosomes. It protects against premature loss of important notations. This study uses shift mutation that randomly selects two points. The rear point is inserted ahead of the front point.

ELITISM

Elitism has been proven successful in GA searches (Ko 2002). It survives a certain amount of Pareto solutions to the next generation. Thus, every generation contains elite solutions for better evolution. By applying this strategy, the fitness increases from one generation to the next.

REPLACE

Replacement is a process that produced chromosomes eliminate parent chromosomes. In this process, previous population is renewed by the generated offspring. Therefore, the next generation can continuously involve new solutions for evolution.

TERMINATE CONDITIONS

The terminate conditions provide the criterion for stopping the evolutionary process. In general, evolutionary process is terminated by iterations and/or required fitness.

EXPERIMENTS

Production data experimented in this section is acquired from Benjaoran et al. (2005). In this case, prefabricator has two A type moulds, two B type moulds, and one C type mould. The experiment includes ten elements, which provides 10! combinations. Obviously, it is not possible to make efficient weekly work plans manually for 10! combinations of sequences within a few weeks. The proposed multi-objective GA is thus applied to the case. Experimental result displayed in Table 1 is an average for 20 runs. Observing the table, MOGLS achieved accuracy 82.56%. Accuracy defined in the study is the ratio of Pareto solutions correctly obtained using the MOGLS. By the contrast, arranging precast production schedules manually is time-consuming and the quality is depending on scheduler's knowledge and experience.

Table 1: Experiment Results for Multi-Objective Problem

Solver	Derived number of Pareto solution	Correct number of Pareto solution	Accuracy
MOGLS	21.34	17.62	82.56%

Precast elements occupy large spaces. It is not reasonable if buffer sizes between stations are ignored. Otherwise, production schedules are not realistic since fabricator provides precast fabrication with a finite space. In this case, maximum buffer sizes between stations are set as five. Experiment results are shown in Table 2.

Table 2: Experiment Results for Multi-Objective Problem with A Finite Buffer

Buffer Size	Makespan	Penalty	Required buffer size
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

Observing the results, maximum required buffer size for the production system is two. Therefore, buffer size has no impact on makespan and cost of penalty when buffer size is larger than two. By the contrast, if buffer size is smaller than the required, both makespan and cost of penalty increases.

CONCLUSIONS

This study describes precast production process with a mathematical model. A multi-objective GA developed based on MOGLS is proposed to solve the model. Multi-objective considered in the study is to minimize makespan as well as cost of penalty. Two experiments were used to demonstrate the effectiveness of applying multi-objective GA in making weekly work plans. Experimental results show that the proposed method can obtain a set of optimum production sequences for decision-making. In addition, considering buffer sizes between stations has been proven crucial by the experiment. The information provided by GA can assist foremen to make proper weekly work plans.

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