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Overcoming Difficulties in Weekly Work Planning Using Computational Algorithms

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Abstract: Application of lean production concepts to precast concrete fabrication has been proven promising. However, difficulties encounter while applying lean concepts to precast fabrication. The objective of the study, is to overcome the difficulty when arranging weekly work plans. Current practices of making weekly work plans are fairly basic and depend greatly on experience, resulting inefficient resource utilization and even late delivery. To enhance weekly work planning, this research develops a flowshop sequencing model. In the model, constraints encountered in practice and buffer sizes between stations are taken into account. A multi-objective genetic algorithm is then used to search for optimum solutions with minimum makespan and minimum tardiness penalty. The performance of proposed method is validated using two case studies. 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 sequences, model, buffer

INTRODUCTION

Precast construction is a method to build up constructions by prefabricated concrete elements. Precast fabricators deliver elements to construction site according to its erection schedule. Building up constructions using precast elements can reduce uncertainty than those cast in the construction site. In addition, it fits in with the needs of industrial process. As a result, precast fabrication in the construction industry can be categorized as manufacturing. Different production plans can induce different throughput. Engineers therefore, endeavour to derive optimum production plans. Nevertheless, tradeoffs and conflictions in the precast production systems increase difficulties in arranging optimum work plans.

Precast fabricators arrange production schedule in weeks. However, current practice of making weekly work plan depends on foremen's experience. In addition, fabricators manually arranging weekly work plans frequently results late delivery and wastes production resources (Dawood, 1993; Chan and Hu, 2002a). Recently, researchers have started on using computational techniques to deal with scheduling issues. Chan and Hu (2002b) 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 with a multi-objective GA. Multiple objective in their study includes minimum machine idle time, minimum late delivery penalty and minimum makespan. Previous studies have proven that precast production is a flowshop production. In addition, production resources have crucial impact on throughput.

The objective of the study, is to overcome the difficulties in making weekly work plans using computational algorithms. So that applicability of the determined work plans can be enhanced. To achieve the goal, precast production process is modelled. By considering prefabricator's objectives, a multi-objective GA is used to solve the model. The study firstly 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.

LEAN PRECAST PRODUCTION SYSTEMS

The promise of applying lean concepts to precast concrete fabrication has been studied by Ballard *et al.* (2002) and Ballard *et al.* (2003). In the investigation, the researchers confirmed the applicability of lean concepts and techniques to the management offabrication

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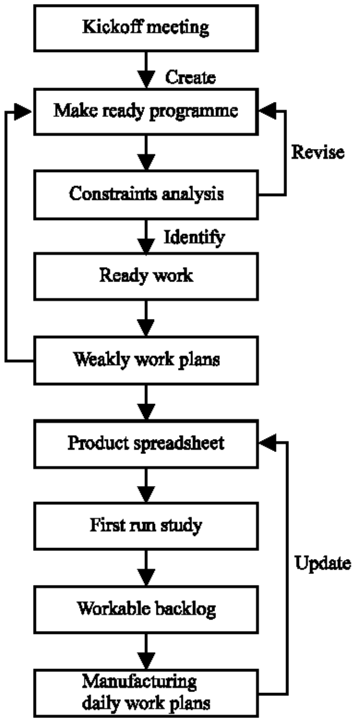

Fig. 1: Process of applying lean concepts ton precast concrete fabrication (Ballard *et al.*, 2002)

processes. A make ready process is addressed in their papers and is 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. In the figure, while making weekly work plans, numerous combinations of sequences increase the difficulties in this activity. A set of relatively efficient solution is required for the situation.

PRECAST PRODUCTION PROCESS

Precast production is a flowshop production that can be divided into 6 steps, namely mould assembly, placement of reinforcement and all embedded parts, concrete casting, curing, mould stripping and product finishing. Mould assembly is to provide mould with a specific dimension for element. In general, fabricators use steel mould for a durable purpose. Precast concrete primarily contains two kinds of materials i.e., concrete and steel bars. Reinforcement and embedded parts are placed in their positions after the mould is complete. Embedded parts are used to connect and fix with other elements or with structure when precast elements are assembled. 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 legal strength may damage elements. 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 of production is product finishing. Minor defects such as scratch, peel-offs, uneven surfaces, etc. are treated in this step.

Traditional flowshop sequencing problem regarded production as a continuous flow (Hopp and Spearman, 2000). However, precast production owns activities that can be done after working hours. Typical equation shown in Eq. 1 that used to calculate completion time cannot meet the needs in the precast industry.

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

Notations used in Eq. 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, Eq. 1 is reformulated as Eq. 2.

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

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

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. Curing is a special task differing from other manufacturing. 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 mould A, element 3 with mould A cannot be started fabrication until element 1 releases mould A. The example demonstrates a situation that fabrication waits for mould, which frequently happens in practice. In the process of scheduling, sequence of moulds is arranged according to the number of moulds and types of moulds.

MULTI-OBJECTIVE GENETIC ALGORITHM

The study adopts the Multi-Objective Genetic Local Search Algorithm (MOGLS) proposed by Ishibuchi and Murata (1998) to search for optimum work plans. The evolutionary process of MOGLS includes 11 activities. Each of them is explained as follows.

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

Initialize population: The variation of initial solution with higher fitness value can improve searching efficiency. To provide an equal chance for every state space, a set of initial solutions are randomly generated. Those chromosomes offer a base for further evolutionary process.

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

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

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

Update pareto solution: Solutions that is better than any other on at least one of two objectives, e.g., makespan and tardiness penalty is called Pareto optimal (Evans, 1994; Tamaki, 1996). To make sure that derived solutions conform to the definition of Pareto solution, every generation has to update Pareto solution pool. 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.

Select: Selection operator is used to select chromosome according to its fitness. Higher fitness value has higher chance for survival. The purpose of the selection operator is to choose fitter chromosomes for evolving better generations. The study adopts roulette-wheel method for selection (Goldberg, 1989). For population size N_{pop} and elitism number N_{elite}, every generation selects (N_{pop}-N_{elite}) chromosomes.

Crossover: GA extends searching space by crossover operator. The operator produces next generation by exchanging partial information of parents. The resulting generation represents a new set of solution. This study uses two-point crossover that randomly determine two points. 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. The study uses shift mutation that randomly selects two points. The rear point inserts in advance of the prior point, then the whole gene shift back forward.

Elitism: Elitism has been proven successful in GA (Ko, 2002). It survives a certain amount of Pareto solution to the next generation. So every generation contains elite solutions for better evolvement. Applying the strategy, fitness increases generation by generation.

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

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

EXPERIMENTS

Production data experimented in this section are acquired from Benjaoran *et al.* (2005) as shown in Table 1. In this case, prefabricator has two A moulds, two B moulds and one C 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. Experiment result displayed in Table 2 is an

Table 1: Production data

Job No.	Mold type	Production time				Costs of penalty		
		Mold assemble	Parts placement	Concrete casting	Mold stripping	Product finishing	Inventory	Late delivery
1	A	2	1.6	2.4	1	A	1.6	2.4
2	B	3.4	4	4.0	2	B	4	4.0
3	A	0.8	1	1.2	3	A	1	1.2
4	A	0.6	0.8	1.0	4	A	0.8	1.0
5	C	3	3.6	2.4	5	C	3.6	2.4
6	A	3	3.2	3.0	6	A	3.2	3.0
7	C	1.3	0.9	2.4	7	C	0.9	2.4
8	B	1.7	1.4	1.1	8	B	1.4	1.1
9	A	2.2	1.8	1.2	9	A	1.8	1.2
10	C	1.6	3.2	2.3	10	C	3.2	2.3

Table 2: 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%

Table 3: 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

average for 20 runs. Observing the accuracy, MOGLS is good enough for arranging precast production schedules comparing to currently manual practice.

Unlike regular manufacturing, 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 3.

Observing the results, maximum required buffer size for the production system is two, which is arrived according to production constraints through GA evolvement. 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 buffer size, both makespan and cost of penalty increases.

CONCLUSION

The 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 are used to demonstrate the effectiveness of applying multi-objective GA in making weekly work plans. 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. Arranging weekly work plans using the proposed method can overcome the difficulties in sequence optimization and buffer size analysis. Hence, applicability of the determined work plans can be enhanced. Contrasting with Material Requirement Planning's (MRP) approach where the focus is on station utilization and scheduling, the study arranges job sequences by considering status of the system that have been pre-analyzed by a lean precast production system.

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