A Stochastic Optimization Approach of Flow Shop Sequencing Problem for On-time Delivery of Precast Components

Mohamed Mamdouh Yusuf[1], Ahmed Karam[2] and Amr B. Eltawil[1]

[1]*Industrial Engineering and Systems Management, Egypt-Japan University of Science and Technology (E-JUST), PO box 179, New Borg Elarab City, Alexandria 21934, Egypt*

[2]*Mechanical Engineering Department, Faculty of Engineering at Shoubra, Benha University, 108, Cairo, Egypt*

Keywords: Precast Industry, Discrete Event Simulation, Flow Shop Sequencing, Stochastic Processing Times, Simulation-based Optimization, Optquest® for Arena®.

Abstract: Recently, the flow shop sequencing problem in precast plants has been witnessing remarkable interest from many researchers. This paper contributes to recent literature by providing a simulation-based optimization approach to solve the precast flow shop sequencing problem taking into account the uncertainty of processing times of precast production operations. The proposed approach is developed by integrating a Discrete Event Simulation (DES) model, which is built to capture the realistic features of precast production activities, and OptQuest® to find the optimum sequencing of Precast Components (PCs). The proposed approach is validated against another approach from literature. In addition, its practicability is put to the test by applying the proposed approach to a real case study. The obtained results indicated that pre-casters can use this approach to attain better PCs sequences than that based on a rule of thumb.

1 INTRODUCTION

Precasting is a kind of industrialized building system which refers to the process of shifting some construction operations from the field to off-site workshops, where construction components can be produced with higher quality, in less time, lower prices and in a leaner and greener way than the traditional construction practice (Sacks et al., 2004). By virtue of their advantages, Precast Components (PCs) were used by 56% of construction projects in Finland, and by 28% in Germany, 26% in Britain, and about 20% in Spain (Sacks et al., 2004).

However, the precast industry faces many challenges which can be cushioned by proper management of its multi-echelon supply chain, starting from material supplying and ending with installation at construction sites (Wang et al., 2018b). This paper focuses only on production scheduling in precast plants where production managers shoulder ordering of PCs to be processed through a number of sequential operations to ensure on-time delivery of PCs to the construction sites. So, it is a typical flowshop sequencing problem. Early delivery of PCs leads to higher inventory costs and double handling of PCs at the construction site. However, lateness of PCs causes higher direct and indirect costs due to project delay. The problem is worsened by the fact that each type of PC has different processing times on the different production operations, and the managers only depend on know-how and hands on experience to tackle this problem, which in turn leads to suboptimal PCs sequences (Wang et al., 2018a). So, there exists a need to provide the production managers with a decision support tool to help them in scheduling of PC production efficiently in order to meet due dates and maximize resource utilization to achieve satisfactory return on investment.

until now, a plethora of researchers addressed the precast production scheduling problem by using different techniques such as mathematical programming methods and simulation models. Most of these studies considered the processing times of PC production operations as deterministic times. Recently, the stochastic nature of precast processing times was claimed to be considered in the precast flow shop sequencing problem only by (Wang et al., 2018a). They developped a two-phase sequential approach which firstly generates near optimal PCs schedules obtained by a Genetic Algorithm (GA), and then a DES model is used to evaluate performance of these PCs schedules under stochastic processing

Yusuf, M., Karam, A. and Eltawil, A.
A Stochastic Optimization Approach of Flow Shop Sequencing Problem for On-time Delivery of Precast Components.
DOI: 10.5220/0007309602450252
In *Proceedings of the 8th International Conference on Operations Research and Enterprise Systems (ICORES 2019)*, pages 245-252
ISBN: 978-989-758-352-0

times. In other words, it is a simulation based evaluation approach which does not guarantee full integration between simulation and optimization, as explicitly mentioned by (Wang et al., 2018a). To improve, this paper presents a simulation-based optimization approach to obtain optimum PCs production schedules with consideration of the stochastic nature of the problem to achieve just in time delivery of PCs. In doing so, a DES model is integrated with an optimization module. After verification and validation of the proposed approach, it is used to find the near optimum PCs production schedules in a real case study.

The rest of the paper is organized as follows, previous studies of precast production planning are reviewed and related research gaps are identified in section 2. Section 3 illustrates the operations to produce and deliver PCs to construction sites while section 4 provides a detailed explanation of the developed simulation-based optimization approach. Numerical experiments are elaborated in section 5. Finally, conclusions are discussed in section 6.

2 LITERATURE REVIEW

The literature on precast production planning is plentiful, and previous researchers dealt with it by using either mathematical programming methods or discrete event simulation models as will be illustrated later in sections 2.1 and 2.2, respectively. Finally, research gaps are identified in section 2.3.

2.1 Precast Production Scheduling using Mathematical Programming

Despite that literature is riddled with many studies on production scheduling (Yenisey and Yagmahan, 2014), these studies did not fit the precast production scheduling problem (Chan and Hu, 2001). So, numerous academics are avid for solving this problem by means of mathematical modeling. (Chan and Hu, 2001) was the first to model the precast sequencing problem as a flow shop sequencing problem with the objective of minimizing the makespan or Tardiness and Earliness (T&E) penalty cost. They made it more realistic by distinguishing between daily working and non-working hours, and classifying production activities into interruptible or uninterruptible and sequential or parallel activities, as will be illustrated in section 3. Their model was deemed to be a stepping-stone because subsequent researchers enhanced it by considering ignored resources or adding other objectives. For example, moulds were considered by the same authors in (Chan and Hu, 2002), however, the competition between PCs on limited moulds was simulated by (Benjaoran et al., 2005) who calculated the PC waiting times due to mould scarcity; they used a multi-objective function to minimize the total flow time, machine idle time and T&E penalty cost. Moreover, mould planning was addressed carefully by (Hu, 2007), who sought for minimizing the number of required moulds and levelling its usage. To improve the models, the buffer capacity between production processes as a limited resource was added by (Ko and Wang, 2011), who used a multi-objective function to minimize the makespan and T&E penalty cost. By the same token, (Yang et al., 2016) not only considered the previous resources but also included pallets, capacity of the curing chamber and the number of production lines to the model. Their objective was to reduce idle time, T&E penalty cost, inventory cost, makespan and PC changeover, simultaneously. Recently, (Wang and Hu, 2017) expanded this model by including three ignored stages in the precast supply chain which are, mould manufacturing, storage and transportation to construction sites, with the objective of cutting T&E penalty costs.

With respect to the applied optimization algorithm, a Genetic Algorithm (GA) was used in the previous studies, by virtue of its performance to find near-optimal solution for such nondeterministic polynomial (NP)-hard problems, except (Chan and Hu, 2002) who applied constrained programming method.

2.2 Discrete Event Simulation-based Approaches Applied to Precast Production

Simulation modelling is preferred over mathematical modelling in analysing large problems of real and complex systems characterized with uncertainty (Law, 2007). Moreover, the ability to conduct different scenarios and check their performance is another advantage over analytical methods (Law, 2007). This fact conduced to the adoption of simulation modelling to tackle precast production planning issues in many studies. Based on the purpose of using simulation, these studies can be categorized into two types: studies applied simulation based evaluation approach and others used simulation based optimization approach.

In the first type, simulation models were used to evaluate some predetermined scenarios and as a result a conclusion can be drawn according to the purpose of study. For instance, (Chen et al., 2016) used a DES model, as an evaluation tool, to validate the advantages of a proposed precast production method over the traditional one in terms of minimizing the makespan and maximizing resource utilization. A DES model was used by (Wang et al., 2018a) to compare between ten PCs production schedules pre-generated by optimizing a mathematical model using GA. The same authors enhanced their model to simulate different risks which disturb the precast supply chain, (Wang et al., 2018b). By using an applied simulation based evaluation approach, they prioritized the identified risks based on their detrimental impact.

In the second type of these studies, the researchers fully integrated simulation with search techniques, to generate a new set of solutions after evaluating an objective function defined in the simulation model. This process continues until a predefined stopping criteria is met. For example, (Cheng and Yan, 2009) coupled a messy GA and CYCLic Operation NEtwork (CYCLONE), a simulation language, to search for optimum resource allocation in order to both minimize hiring cost and maximize production rate of a precast plant. Different kinds of production resources were simulated in this study such as molds, labors, trucks, cranes, hydraulic jacks and truck mixers. Also, (Al-Bazi and Dawood, 2018) integrated GA and simulated annealing, respectively with Arena® simulation model; the purpose was to find the optimum allocation of multi skilled labors in a precast plant with the objective of reducing crew allocation costs. Arena® is a simulation software enables both discrete and continuous simulation simultaneously. Moreover, (Arashpour et al., 2016) used Tabu search and Arena® model to meet contracted due dates of PCs by finding the optimum PCs production sequence while considering multi-skilled resources and wasted time due to switching from one PC type to another. However, the realistic nature of the precast production activities, identified by (Chan and Hu, 2001) and mentioned in section 2.1, was not considered in their model.

2.3 Research Gaps

After reviewing the aforementioned studies, some research gaps can be deduced and discussed along the following fronts.

- Despite the superiority of simulation modelling over mathematical modelling in capturing the characteristics of complex systems and incorporating uncertainty, precast production planning issues addressed by using mathematical models were more diverse than that addressed by simulation models. So, a research gap needs to be filled by applying simulation modelling not only to consider uncertainty but also to regard other important factors in the precast industry such as inventory management, logistics, multiple production lines, buffer space between workstation, materials supply, coordination with contractors at construction sites, risk management, incorporation of valuable assets such as trucks, cranes and steamers.
- In addition to that, the realistic nature of precast production activities was simulated only by (Wang et al., 2018a), who built their model based on the mathematical formulation illustrated in (Chan and Hu, 2001) and (Wang and Hu, 2017). This formulation does not reflect other realistic conditions in precast production such as waiting time due to shared resources like moulds, cranes and multi-skilled labours, hiring additional crews at each process, limited capacity of curing and storing processes, limited production space between processes and specifying failure data for each type of production resources. So, there exists a need to develop a more general model to enable practitioners to experience the different production conditions without the need to reformulate the mathematical model to suit each condition.
- Besides, reviewing the studies in section 2.2 shows that researchers used only metaheuristics in their simulation based optimization methodology due to their advantages. However, other simulation optimization methods may be more beneficial than metaheuristics to deal with noisy functions and correlated decision variables in case of applying cross-entropy methods, or to reduce computational time by using the Response Surface Methodology (RSM) which will be of great importance in case of more complex models of precast production planning in the future. In a similar vein, commercial optimization toolboxes can be used due to its capability, credibility and usability.

To bridge these gaps, this paper is intended to develop a more general simulation model to reflect the nature of precast production activities without the need to use case dependent mathematical equations. This model is linked with an optimizer to solve the precast flow shop sequencing problem with considering uncertainty in processing times of precast production activities.

3 DESCRIPTION OF THE PRECAST PRODUCTION PROCESS

To be ready for installation on the construction site, PCs have to be processed through nine sequential operations (from M1 to M9), (Wang and Hu, 2017).

M1- Mould manufacturing: Due to lack of standardization, pre-casters may receive PC orders inconsistent with their own moulds. If that is the case, new moulds should be manufactured.

M2- Mould assembling: assemblers have to prepare moulds by fastening, cleaning and oiling its sides to ensure smooth PCs surface and effortless demoulding.

M3- Reinforcement setting: reinforcement and other predetermined parts are placed in their locations according to shop drawings.

M4- Casting: ready mix concrete is poured, compacted and levelled.

M5- Curing: PCs are either transferred to the steam curing chamber or covered by water proof membrane, to ensure its strength development and durability.

M6- Demoulding: stripping moulds and extracting PCs.

M7- Finishing and repairing: after taking out PCs, they should be checked and any imperfections have to be fixed.

M8- Storing: the PCs are stored at the stockyard to ensure delivery strength.

M9- Transportation: in this process, the PCs are transferred to the construction sites by using trucks.

These nine processes can be classified into interruptible and sequential (M1, M2, M3, M6 and M7), uninterruptible and sequential (M4), uninterruptible and parallel activities (M5, M8 and M9), (Wang and Hu, 2017). With respect to interruptible activities, it is not permitted that working on the PCs exceeds an allowable working time denoted by H_w. If working on a PC needs time beyond H_w, it will be continued on the next day, as shown in Figure 1.a. However, in case of uninterruptible activities, labors are allowed to work overtime hours denoted by H_A if they can finish working on a PC. If they cannot, the whole working on this PC is delayed to the next day, as shown in Figure 1.b. In parallel activities, more than one PC can be processed, simultaneously. On the contrary, only one PC can be processed in sequential activities. Moreover, PC curing and storing can be extended overnight in case of requiring time beyond H_w in contrast to transportation activity, as shown in Figures 2.c and 2.d, respectively.

4 THE PROPOSED SIMULATION-BASED OPTIMIZATION APPROACH

The proposed approach is based on iterative interaction between a DES model and OptQuest® which is a commercial optimization software fully integrated with Arena®. The integration mechanism is as follows: OptQuest® finds trial schedules for the simulation model. The quality of the schedules is evaluated through running the simulation model. The evaluation of the schedules is feedback to OptQuest® in order to search for new trial schedules. Once, a termination condition is held true, the iterative process is stopped and the best schedule is output. In

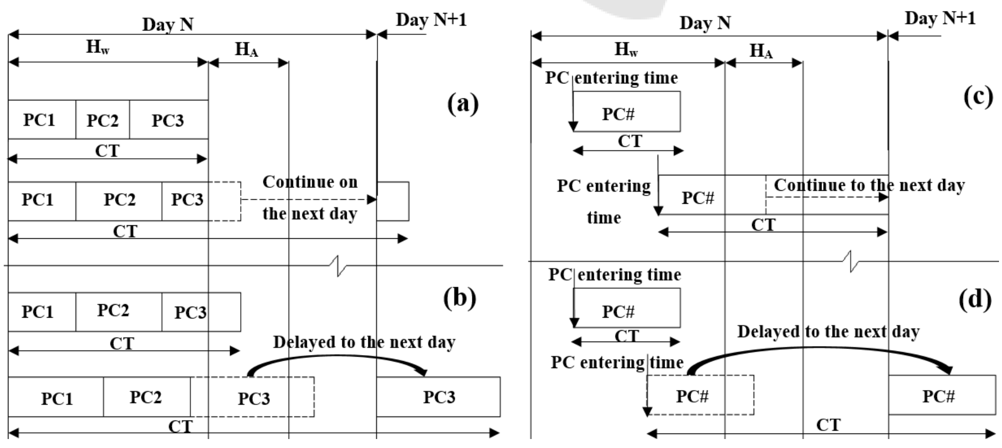

Figure 1: Completion Time (CT) in different classes of precast production activities.

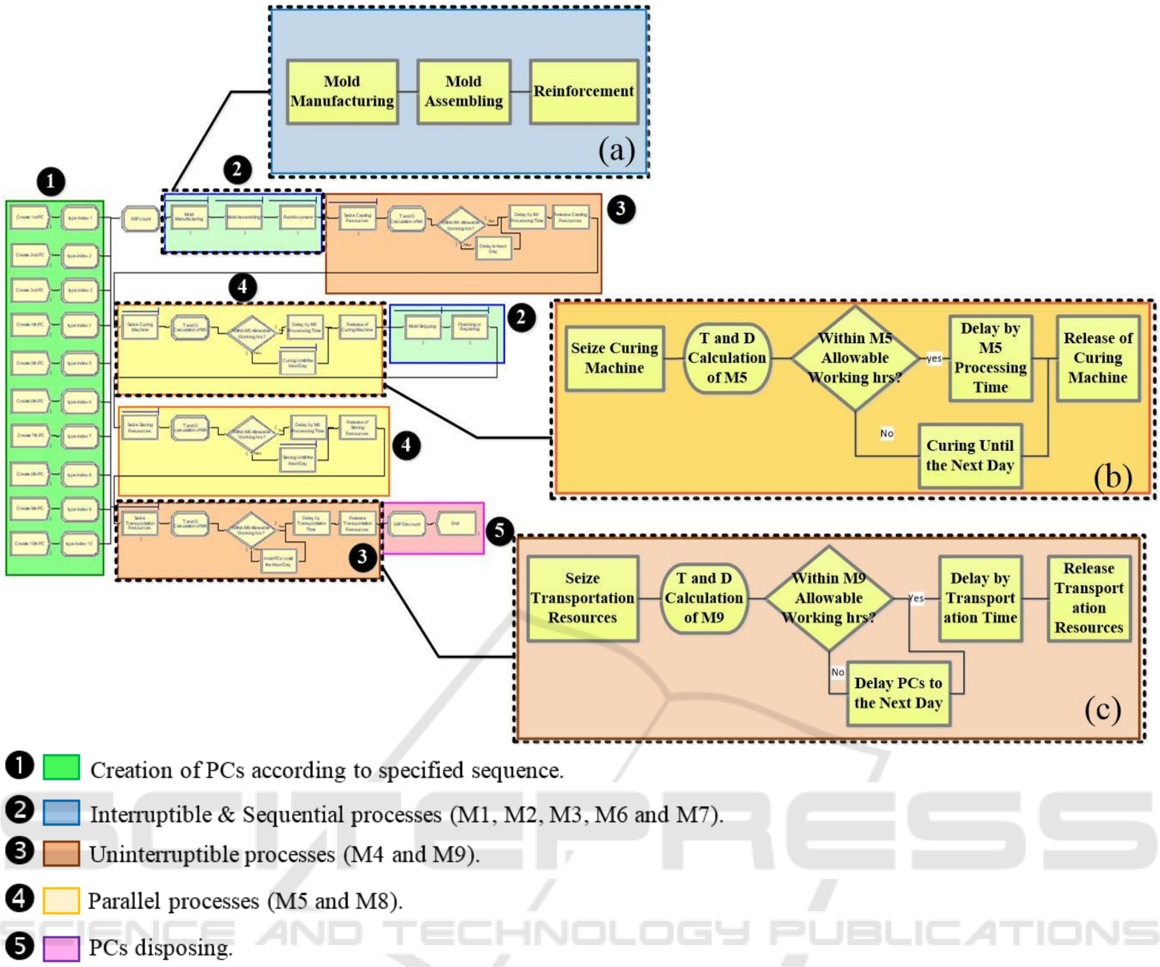

Figure 2: Arena simulation model of precast workshop; (a) The representation of the interruptible and sequential activity by using Arena®'s "Process" module; (b) The representation of the parallel activity by using Arena®'s "Seize", "Decide", "Delay" and "Release" modules; (c) The representation of the uninterruptible activity by using Arena®'s "Seize", "Decide", "Delay" and "Release" modules.

the following sections, the simulation model and the optimization procedure are described in detail.

4.1 The Simulation Model of the Precast Production Activities

The realistic nature of each precast production activity is simulated in a more general model than that of (Wang et al., 2018a), as shown in Figure 2. For instance, interruptible and sequential activities such as mold manufacturing (M1), mold assembling (M2), reinforcement (M3), mold stripping (M6) and finishing/repairing (M7) can be modeled by using only Arena®'s "Process" modules, as shown in Figure 2.a, and identify a resource schedule with unit capacity and "Preempt Rule", available during normal working hours (H_w). Regarding the parallel activities (curing M5 and storing M8) and the uninterruptible activity (casting M4), they are modeled by using "Seize", "Delay" and "Release" modules, as shown in Figures 3.b and 3.c. After seizing the respective resources, the completion time of each PC until this stage must be examined to decide whether this PC can be processed during the remaining hours of a typical working day (normal working hours (H_w) for M5 and M8; normal working hours (H_w) + allowable overtime (H_A) for M4). If it is not the case, the PC is delayed to the next day for the casting process, as shown in Figure 2.c. As for the curing or storing processes, the PC is left in the curing machine or the storage yard until the next day, as depicted in Figure 2.b. The resources' schedules with unlimited capacity during 24 hours are identified for the M5 and M8 processes, but only a unit resource capacity is available during (H_W + H_A) hours for the M4 process. It is worth mentioning that all the scheduling rules are set to "Preempt" for all activity types. Finally, the transportation process (M9) is an uninterruptible activity with unlimited capacity.

The developed simulation model is built on some assumptions illustrated through the following points:
1- Every PC has to be processed throughout all of the operations starting from mold manufacturing (M1) and ending with transportation (M9).
2- It is not possible that a PC is processed on more than one operation simultaneously.
3- Every process can work only on one PC within a time period except curing (M5) and storing (M8) which have an unlimited capacity.
4- Rescheduling of PCs is not allowable. In other words, the PCs processing sequence will not be manipulated until the exit of the last PC even if it could improve objective function.
5- The considered resources are the molds and labors only, and there are no shared resources. To clarify, each process has its own crew and each PC has its specific mold.
6- The storing and transportation processes (M8 and M9) are considered under daytime scenario, as illustrated in (Wang and Hu, 2017).
7- Ramifications of resources breakdown are not taken into consideration.
8- First-In-First-Out (FIFO) is adopted as a priority rule at each task.

4.2 The Optquest® Optimization Module

OptQuest® depends mainly on scatter search, and Tabu search as a secondary algorithm. In addition, it uses neural network to speed up searching process. By using these techniques, OptQuest® establishes a new set of decision variables after evaluating value of objective function retrieved from Arena® simulation model (Bradley, 2007). This process is iterated in a cyclic manner until a predefined stopping criteria is achieved; more details on how it works can be found in (Laguna and Marti, 2003). In order to commence the optimization process, decision variables, constraints and objective function need to be identified to OptQuest®. As for the constraints, they are formulated to guarantee that each PC has a unique ordering. For more clarification, suppose that there a number of PCs n and each PC must be processed with a sequence number i, where $i \in \{1, \ldots, n\}$. We define a bianry variable, x_{ij} which is one if the PC j , where $j \in \{1, \ldots, n\}$, is processed in i^{th} order and zero otherwise.

$$\sum_{j \in n} x_{ij} = 1 \; \forall \, i \in n \tag{1}$$

Constraint set (1) ensures that in any i^{th} order, one and only one PC is processed.

$$\sum_{i \in n} x_{ij} = 1 \; \forall \, j \in n \tag{2}$$

Constraint set (2) ensures that each PC j must be processed in only one i^{th} order.

OptQuest® generates new sets of feasible sequences of PCs after evaluating the objective function though running the simulation model. The objective function aims at minimizing tardiness and earliness penalty cost, as defined in equation (3).

$$f_{pn}(s) = Min \sum_{j=1}^{n} \left[\alpha_j Max\left(0, C_j - d_j\right) + \beta_j Max\left(0, d_j - C_j\right) \right] \tag{3}$$

Where $f_{pn}(s)$ is the total tardiness and earliness penalty costs for n PCs of sequence s of precast components ; C_j is completion time of each PC j at the last process; d_j is contracted due date for each PC j; α_j and β_j are tardiness and earliness penalties for each PC j.

5 NUMERICAL EXPERIMENTS

In this section, numerical experiments are carried out to investigate the performance of the proposed approach. Firstly, section 5.1 shows the validation of the proposed approach by making a comparison with an approach existing in literature. In section 5.2, the proposed approach is applied to a case study.

5.1 Validation of the Proposed Approach

The developed approach was validated by comparing its results with that provided by (Chan and Hu, 2001). In their work, they proposed a GA to solve the precast flow shop sequencing problem. The objective was to minimize makespan by sequencing six PCs on six operations, starting from mold assembling (M2) and ending with finishing/repairing (M7), and compared their results with heuristic rules from literature. In order to compare our approach with the approach of (Chan and Hu, 2001), we modified our objective function into theirs and also, we conducted a purely

Table 1: Comparison of our approach with the results reported by (Chan and Hu, 2001).

Objective function	The proposed approach	Heuristic algorithms used in (Chan and Hu, 2001)					
		Palmer's heuristic	Gupta's heuristic	CDS heuristic	RA heuristic	EDD rule	GA
Minimize Makespan (Hours)	48.5	50.6	50	50	49.4	51	48.5

deterministic run of our approach by considering the deterministic times as in the work of (Chan and Hu, 2001). In other words, their example is replicated by using the proposed approach and a comparison is made between the results, as shown in Table 1. It can be noticed that the proposed approach could obtain optimal solution that is as good as that provided by the GA proposed by (Chan and Hu, 2001). In addition, the optimal solution of the proposed approach outperforms the other heuristic rules.

5.2 Case Study

The purpose of this section is to test the performance of the proposed approach within a realistic problem taken from literature (Wang et al., 2018a). In this case study, it was required to order ten PCs on nine processes (from M1 to M9) with the objective of minimizing T&E penalty costs. Since the processing times of the production operations are stochastic (the processing times obey triangular distribution), ten replications are used based on preliminary analysis to achieve reasonable half-width of the 95% confidence intervals of the resulted penalty cost. Before starting the optimization process, the initial solution is selected to be 7-9-2-5-4-10-8-6-3-1. This solution is based on a heuristic rule often used by pre-casters in reality, (Chan and Hu, 2001). The penalty cost that resulted from applying this heuristic sequence is 229.6$. Table 2 lists the optimum solutions of the case study obtained by applying the proposed approach under different number of simulation iterations, accompanied by the average penalty costs and the half-width of the 95% confidence intervals. These simulation experiments were conducted by using a laptop with Intel(R) Core(TM) i7-6500U 2.50 GHz processor, 8.00 GB of RAM and running a Windows 10 Education 64-bit operating system. Obviously, the adoption of the proposed approach can lead to better PCs production sequences than that based on the heuristic rule. Interestingly, the proposed approach took only four minutes to provide a PC production sequence (sequence obtained after 100 iterations) that saves about 11% of penalty costs in comparison with the heuristic sequence, which in turn proves the practicability of the proposed approach in case of making such urgent operational decisions like PCs sequencing. Figure 3 shows the fast convergence of the proposed approach after 1000 simulation iterations. This figure indicates that the penalty cost was plunged during the first hundred iterations and there was no improvement in the objective function after 400th iteration.

Figure 3: Convergence of the proposed approach to solve the case study.

Table 2: Results of the case study after applying the proposed approach.

No. of simulation iterations	Solution time (Min)	Optimum PCs sequence	Average penalty cost ($)	Half-width penalty cost ($)
1000	32	3-2-9-7-4-5-10-8-6-1	195.2	1.35
500	16	2-1-9-7-4-5-8-10-3-6	196	0.17
100	4	1-9-2-4-7-5-8-10-3-6	203.9	0.22

6 CONCLUSION

Previous studies addressed precast production planning by using either mathematical programming methods or simulation models. However, the uncertainty of processing times when determining optimum PCs schedules to achieve on-time delivery of PCs was seldom addressed. To fill this gap, a simulation-based optimization approach is developed in which a discrete event simulation model was developed by using Arena® software based on precast flow shop sequencing formulation. Then, the developed model is linked with OptQuest® (an optimization package) to search for optimum PCs sequences that minimize deviation from the contracted due dates of PCs. Thereafter, the proposed approach was validated by comparing its results with a published approach from literature. To test its practicality, the developed approach was applied on a case study with the objective of minimizing the tardiness and earliness penalty costs. The obtained results indicated that the optimum sequence can save about 15% of penalty costs in comparison with the results of a heuristic rule.

In future work, multi-objective function to minimize both the penalty cost and production costs can be applied while considering other realistic features of the precast production such as buffer space between production stages and multiple production lines. However, the computation time will be longer due to the complexity of the simulation model. This might call for using other simulation optimization methods such as the response surface methodology to reduce the time needed to make urgent operational decisions in precast plants such as PCs sequencing.

REFERENCES

Al-Bazi, A., and Dawood, N., 2018. Simulation-based optimisation using simulated annealing for crew allocation in the precast industry. *Architectural Engineering and Design Management*, *14*(1–2), 109–126. https://doi.org/10.1080/17452007.2017.1313721

Arashpour, M., Wakefield, R., Abbasi, B., Lee, E. W. M., and Minas, J., 2016. Off-site construction optimization: Sequencing multiple job classes with time constraints. *Automation in Construction*, *71*(Part 2), 262–270. https://doi.org/10.1016/j.autcon.2016.08.001

Benjaoran, V., Dawood, N., and Hobbs, B., 2005. Flowshop scheduling model for bespoke precast concrete production planning. *Construction Management and Economics*, *23*(1), 93–105. https://doi.org/10.1080/0144619042000287732

Bradley, A., 2007. OptQuest for Arena User's Guide. *RS Inc., Ed., Ed*.

Chan, W.-T., and Hu, H., 2001. An application of genetic algorithms to precast production scheduling. *Computers and Structures*, *79*(17), 1605–1616.

Chan, W. T., and Hu, H., 2002. Constraint programming approach to precast production scheduling. *Journal of Construction Engineering and Management*, *128*(6), 513–521.

Chen, J. H., Yang, L. R., and Tai, H. W., 2016. Process reengineering and improvement for building precast production. *Automation in Construction*, *68*, 249–258. https://doi.org/10.1016/j.autcon.2016.05.015

Cheng, T. M., and Yan, R. Z., 2009. Integrating messy genetic algorithms and simulation to optimize resource utilization. *Computer-Aided Civil and Infrastructure Engineering*, *24*(6), 401–415. https://doi.org/10.1111/j.1467-8667.2008.00588.x

Hu, H., 2007. A study of resource planning for precast production. *Architectural Science Review*, *50*(2), 106–114. https://doi.org/10.3763/asre.2007.5016

Ko, C. H., and Wang, S. F., 2011. Precast production scheduling using multi-objective genetic algorithms. *Expert Systems with Applications*, *38*(7), 8293–8302. https://doi.org/10.1016/j.eswa.2011.01.013

Laguna, M., and Marti, R., 2003. The OptQuest callable library. In *Optimization Software Class Libraries* (pp. 193–218). Springer.

Law, A. M., 2007. *Simulation modeling and analysis*, McGraw-Hill New York, 4th edition.

Sacks, R., Eastman, C. M., and Lee, G., 2004. Process model perspectives on management and engineering procedures in the precast/prestressed concrete industry. *Journal of Construction Engineering and Management*, *130*(2), 206–215.

Wang, Z., and Hu, H., 2017. Improved Precast Production – Scheduling Model Considering the Whole Supply Chain. *Journal of Computing in Civil Engineering*, *31*(4), 1–12. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000667.

Wang, Z., Hu, H., and Gong, J., 2018a. Framework for modeling operational uncertainty to optimize offsite production scheduling of precast components. *Automation in Construction*, *86*(April 2017), 69–80. https://doi.org/10.1016/j.autcon.2017.10.026

Wang, Z., Hu, H., and Gong, J., 2018b. Simulation based multiple disturbances evaluation in the precast supply chain for improved disturbance prevention. *Journal of Cleaner Production*, *177*(March), 232–244. https://doi.org/10.1016/j.jclepro.2017.12.188

Yang, Z., Ma, Z., and Wu, S., 2016. Optimized flowshop scheduling of multiple production lines for precast production. *Automation in Construction*, *72*, 321–329. https://doi.org/10.1016/j.autcon.2016.08.021

Yenisey, M. M., and Yagmahan, B., 2014. Multi-objective permutation flow shop scheduling problem: Literature review, classification and current trends. *Omega*, 45, 119–135.