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IMPACT OF THE BUFFER SIZE ON PRECAST FABRICATION

Chien-Ho Ko[1]

ABSTRACT

Buffer sizes between production stations are one factor that influences production performance. Current practices in precast production ignore buffer size between stations typically induce unfeasible production plans. Research questions for this paper are 1) how would buffer sizes between precast production stations affect precast production plans and 2) how could computational techniques help in arranging precast production plans? To answer those questions, a program that considers production resources and buffer size between stations is developed. Impact of buffer sizes on production makespan and delivery is analyzed using a case study. Experimental results show that buffer sizes between stations are crucial for acquiring reasonable and feasible precast production plans. A sufficient buffer size larger than the required buffer size could help achieve a better performance with a shorter makespan and lower costs.

KEYWORDS

Process, production, waste, precast, buffer.

INTRODUCTION

Precast fabrication in the construction industry could be categorized as manufacturing (Ray et al. 2006). Using precast components can reduce uncertainty during construction period since these components are prefabricated at the factory (Boyd et al. 2013). Precast fabricators deliver elements to a site according to its erection schedule. Making production plans is one of the most important tasks in precast manufacturing (Tharmmaphornphilas and Sareinpithak 2013). To enhance the competitiveness of a fabricator, production schedulers face the challenges of satisfying multiple objectives since one may conflict with the others (Chan and Hu 2002).

Due to the large volume of precast components, the fabricator requires a rather large space when manufacturing. Furthermore, since precast components are heavy, they cannot be moved without cranes. While the precast factory is under construction, the facility layout and crane positions are pre-determined. Therefore, the production line is regarded as a resource which cannot be adjusted. The other key factor impacting precast fabrication is the number of molds (West, 2006). Precast fabricators generally use steel

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molds rather than wooden since steel is more durable than wood. However, steel is much heavier and expensive than wood. To reduce the cost of a mold, fabricators endeavor to use as few as possible.

The current practice of making precast production plans depends on the scheduler's experience. Due to inaccurate planning methods, inefficient resource utilization and overstocking are commonplace in the precast industry (De Athayde Prata et al. 2015). Researchers have begun using computational techniques to manage scheduling issues (Benjaoran et al. 2005; Alghazi et al. 2012; Jeon et al 2014). Although precast fabrication requires a rather large space while manufacturing, previous studies have ignored buffer sizes between stations, thereby resulting in unrealistic production schedules.

The objective of this study is to analyze the impact of buffer size between stations on production makespan and costs. A limited buffer size between stations is taken into account in the study. Computational techniques are used to calculate production makespan and penalty costs with different buffer sizes.

INVENTORY WASTE

Toyota has popularized a production system designed to eliminate waste. Designed primarily by former Toyota executive Taiichi Ohno, the system is characterized by low costs, small batch sizes, and diverse production. Ohno defined waste as any activity which fails to comply with the standard efficiency of the production system and does not create value in either the production line or product development flow. Ohno (1988) specified seven valueless activities, namely: 1) overproduction, 2) transport, 3) waiting, 4) inventory, 5) defects, 6) motion, and 7) over-processing.

Precast fabricators strive for business success on delivering productions on time (Ko and Ballard 2005). To achieve this goal, fabricators starts manufacturing precast elements once they receive orders, which generates inventory. This type of waste refers to unprocessed raw materials, work in progress, or goods which cannot be completed. Unnecessary inventory could result excess purchasing of raw materials or manufacturing of larger than necessary batches, which leads to longer lead times, and obsolete or unneeded products. Excess inventory leads to the stagnation of raw materials in storage and added costs for handling and storage (Ko and Kuo 2015). The larger the buffer size, the higher the inventory level. Buffer sizes between production stations may be regarded as a kind of inventory, which influences production flow and inventory cost (Ko 2013).

PRECAST PRODUCTION PROCESS

To analyze the impact of buffer sizes between precast production stations, precast production process is identified. Precast production can be divided into six steps: 1) mold assembly, 2) placement of reinforcement and all embedded parts, 3) concrete casting, 4) curing, 5) mold stripping, and 6) product finishing, as depicted in Figure 1 (Ko and Wang 2010). The mold assembly activity provides a specific dimension. In general, fabricators use steel molds for the purpose of reuse. A precast component generally contains two kinds of materials, i.e., concrete and steel bars. Reinforcements and embedded parts are placed in their positions after the mold is formed. Embedded parts are used to connect and fix with other components or with the structure when the precast components are erected. 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. Moving, erecting, or erecting components before the legal strength is achieved may cause damage. 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.

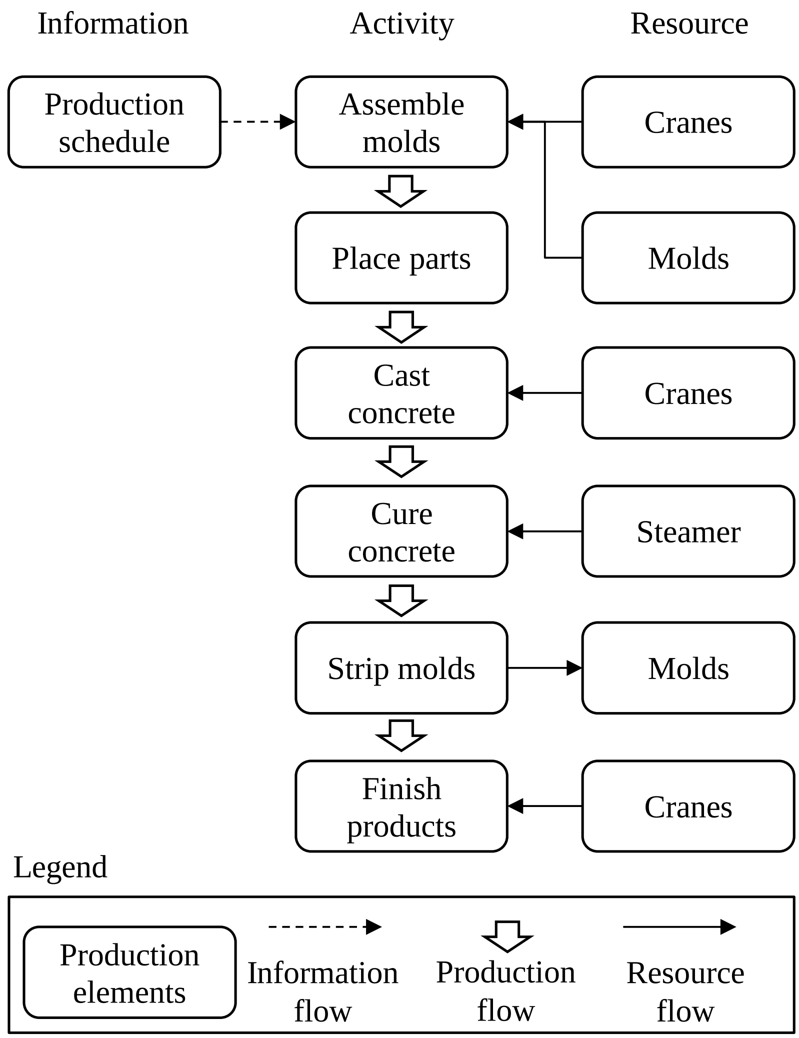

Figure 1: Precast Production Flow

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):

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

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

Eq. (1) assumes an infinite buffer size between stations so that the production flow can be continuous. In practice, due to the large size of the precast elements, the buffer size between stations is limited. As a result, the regular flowshop sequencing model derived in Eq. (1) cannot meet the needs of precast production. This formula is therefore reformulated as Eq. (2):

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

where $WT_{j-1,k}$ is the time for the (j-1)th element in k machine waiting to be sent to buffer, which can be represented by using Eq. (3):

$$WT_{j,k} = \begin{cases} C\left(J_{j-B_k}, M_{k+1}\right) - P_{j-B_k,k+1} - C\left(J_j, M_k\right) \text{....} if \text{..} C\left(J_j, M_k\right) < C\left(J_{j-B_k}, M_{k+1}\right) - P_{j-B_k,k+1} \\ 0 \text{...} if \text{...} C\left(J_j, M_k\right) \geq C\left(J_{j-B_k}, M_{k+1}\right) - P_{j-B_k,k+1} \end{cases} \tag{3}$$

A decision maker faces challenges in achieving multi-objectives while devising production plans. Generally, the goal is to simultaneously minimize cost and production duration. Scheduling performance is therefore evaluated by its makespan and penalty costs (Ko and Wang 2011). Makespan, also called maximum completion time (C), denoting the period needed to complete all jobs, can be calculated by using Eq. (4):

$$f_1(\sigma) = C_{\max} = C\left(J_n, M_m\right) \tag{4}$$

To achieve the goal of delivering products Just-In-Time (JIT), the tardiness cost is considered (Pathumnakul and Egbelu 2006). However, the inventory cost can be decreased by considering the earliness penalty in production scheduling (Sawik 2007). The total penalty costs are computed as in Eq. (5):

$$f_2(\sigma) = \sum_{j=1}^{n} \tau_j \cdot Max\left(0, C_j - d_j\right) + \sum_{j=1}^{n} \varepsilon_j \cdot Max\left(0, d_j - C_j\right) \tag{5}$$

where d_j denotes the desired completion time for job j; τ_j the unit cost of late delivery for job j; and ε_j , unit inventory cost for job j.

MAKESPAN AND PENALTY COSTS ANALYSIS

To understand the impact of buffer size between precast production stations, production makespan and penalty costs are analyzed. This study adopts multi-objective genetic algorithms to automatically calculate production makespan and penalty costs due to different buffer sizes. The mathematical programming model used to minimize makespan and penalty costs is shown in Eq. (6):

$$\begin{aligned} &\text{Minimize z=}\left(f_1(x), f_2(x)\right) \\ &\text{subject to } x \in X \end{aligned} \tag{6}$$

where z represents the objective vector; x the decision vector; and X the feasible area.

Multi-objectives are represented by a weighted sum approach. This target vector minimizes the distance in objective space to a given goal vector. The objective function is obtained in Eq. (7):

$$f(x) = \omega_1\left(f_1(x)\right) + \omega_2\left(f_2(x)\right) \tag{7}$$

where ω_1 and $\omega_2$are positive weights ($\omega_1 + \omega_2 = 1$); $f_1(x)$ the makespan function obtained in Eq. (4); and $f_2(x)$, the penalty function calculated by Eq. (5). The plan generation process is represented in Figure 2 (Ishibuchi and Murata 1998).

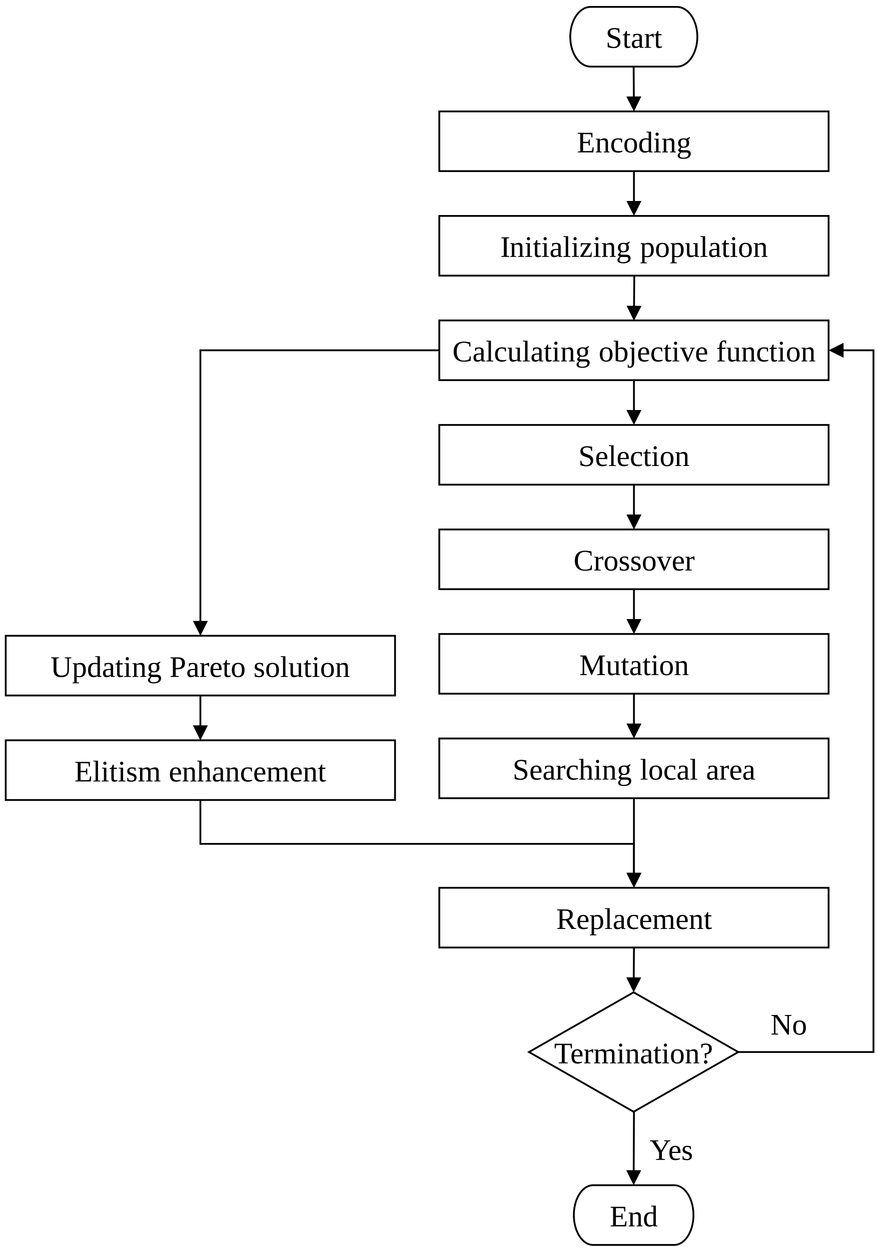

Figure 2: Calculation Procedure for Production Makespan and Penalty Costs

It is time consuming and difficult to manually calculate production makespan and penalty costs. Application software is thus developed. The high-level system use case diagram is demonstrated in Figure 3. Use case diagram is a representation of user's interaction with the system, which shows the relationship between the user and use cases (Gemino and Parker 2009). In the Figure, users are responsible to configure parameters required for arranging production schedules. Parameters settings include algorithm parameters, production information, facilities, and objective functions. Once the parameters have been set, users can use the application to generate production plans. The application user interface is shown in Figure 4.

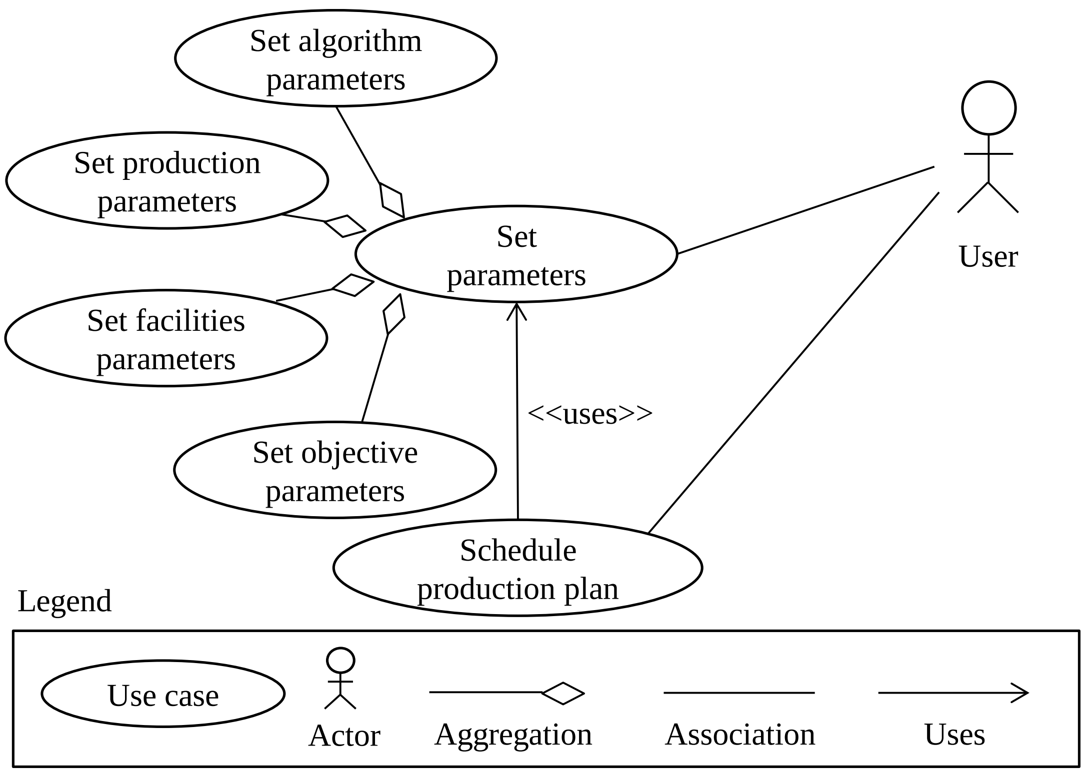

Figure 3: Use Case Diagram

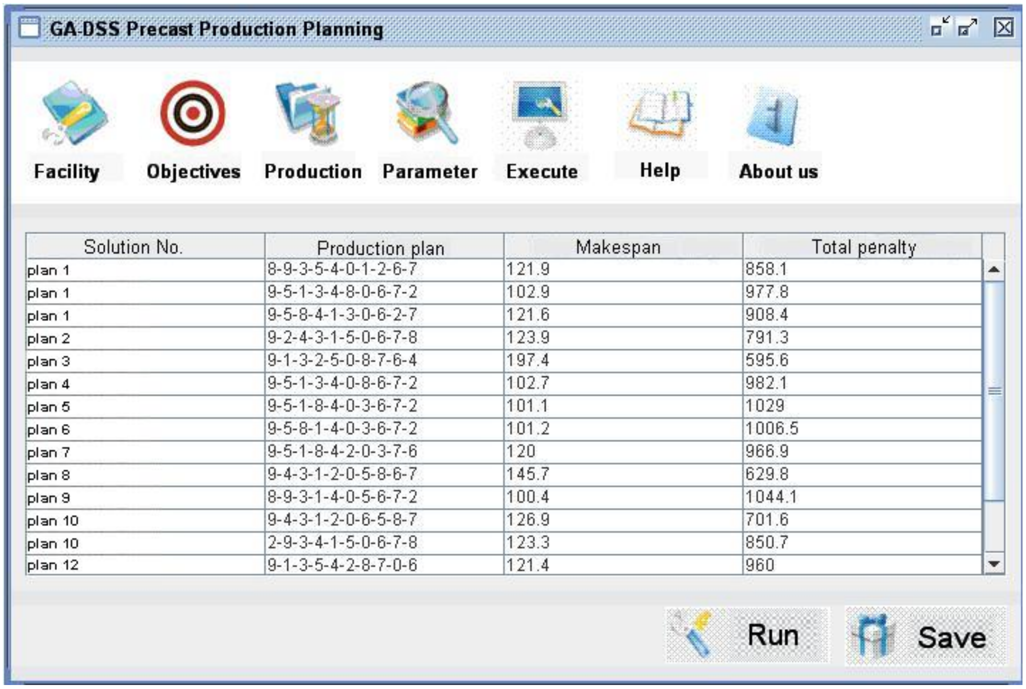

Figure 4: Derived Production Plans

CASE STUDY

To analyze the impact of buffer sizes between production stations on production makespan and delivery, a case study with different buffer sizes is discussed. Production data of the case study is extracted from Benjaoran et al. (2005). Ten precast elements are used in the experiments, as shown in Table 1. The transportation time is included in the makespan. Penalty costs include inventory cost and late delivery penalties. Scenarios with different buffer sizes between production stations are analysed using the developed software. Without the software, it seems difficult to manually calculate production makespan and penalty costs by simultaneously considering production resources, mold type and amount, working hours, and allowable overtime. The results are demonstrated in Figure 5. In the figure, the provided buffer size is the greatest capacity in the production system. In this case study, the maximum buffer size required in the system is two. When the provided buffer size is far larger than two (such as five), it has nearly no influence on the makespan and total penalty cost. However, if the buffer size is smaller than the required buffer size, the makespan and total penalty cost increase. The trends of both makespan and total penalty cost keep descending while larger buffer sizes are provided. In Figure 5, total penalty cost dramatically adjourns at the provided buffer size three and keeps flat after provided buffer size four. An on-time delivery can be reached if buffer size four is provided and no extra penalty cost occurs. On the other hand, minimum makespan can be found at provided buffer size four. The makespan for 10 precast elements cannot be shortened even a larger buffer size is provided. In this case, buffer size four is the most profitable decision for precast fabricators to delivery on time with the lowest inventory cost.

Table 1: Production Data (Benjaoran et al. 2005)

Element No.	Steel mold type	Due day (h)	Penalty costs	
			Inventory	Tardiness
1	A	112	2	10
2	B	112	2	10
3	A	112	1	10
4	A	112	1	10
5	C	208	2	10
6	A	128	2	10
7	C	144	2	10
8	B	144	2	20
9	A	144	1	20
10	C	240	1	20

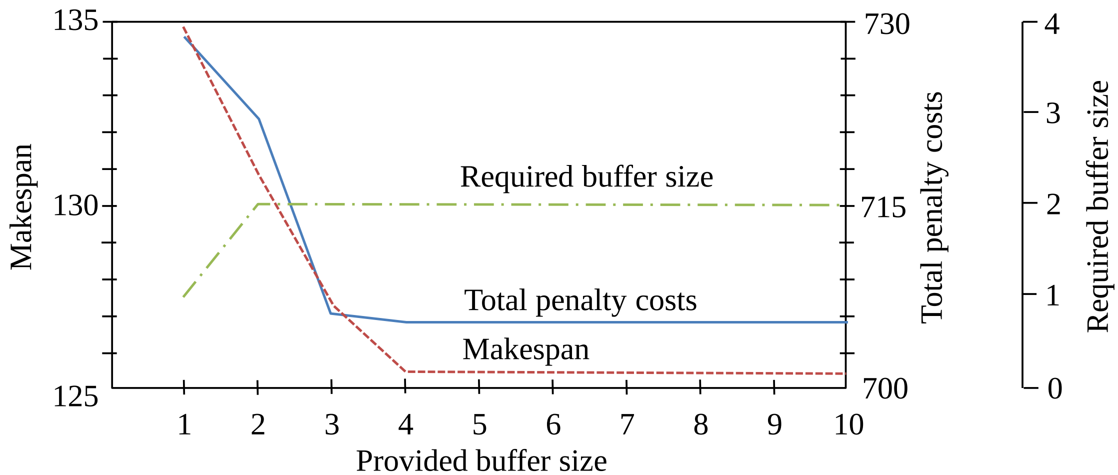

Figure 5: Buffer Size Experimental Results

CONCLUSIONS

Current practice of precast production planning assumes that the buffer between stations is infinite. However, precast elements require a lot of space for moving and storage. Production plans might be unrealistic if the actual buffer sizes are not taken into account. This study deals with the impact of buffer size on production planning. Case study shows that if the provided buffer size is sufficient for the needed buffer size, both makespan and total penalty costs could be reduced. To the contrary, if the provided buffer size is insufficient for the needed buffer size, makespan and total penalty costs increase, due to inflexible resource allocation. An appropriate buffer size for precast fabrication is also related to factory space. Redundant buffer size may add no value to production and need to pay attention for regular maintenance, which is wasteful. The study also found that the provided buffer size could be larger than the needed buffer size. A shorter makespan with lower penalty cost could be reached if sufficient buffer sizes are provided and larger than the needed buffer size.

It is time consuming and complex to manually analyze appropriate buffer sizes between precast fabrication stations. The best decision could be obtained through computer experiments. Production resources, mold type and amount, working hours, allowable overtime, and buffer sizes could be simultaneously considered in the developed application programmed using JAVA language. These computational techniques may assist managers in arranging production plans with a sufficient manner, and provides alternative production plans for decision-making.

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