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Identification of Factors Influencing the Operability of Precast Concrete Construction Shipment Request Forms

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Abstract: Recently, interest in the precast concrete (PC) construction method has been increasing. The PC construction process consists of i) design, ii) production, iii) transportation, and iv) installation. A PC field manager at the site submits a shipment request form to the factory one to three days before the installation of the PC component. Numerous matters should be considered in writing a shipment request form. Incorrect shipment request forms may cause standby resources, waste of resources, premature work conclusion, or excessive work. These issues can lead to an increase in construction costs, replanning of PC component installation, or rework. In order to prevent such problems, PC component installation should be simulated based on the shipment request form. Accordingly, this study aims to identify factors influencing the operability of shipment request forms for PC construction. To this end, this study derived factors influencing i) initiation of the activity, ii) addition or deletion of activities, and iii) an increase or decrease in the activity execution time. As a result, this study identified flow, the features of PC components, condition of PC components, unloading location, installation location, input equipment and labor, number of anchors, number of supports, weather, strike, and accident. Further studies should verify the factors derived in this study based on focus group interviews.

Key words: precast concrete construction, activity-flow model, shipment request forms, operability influencing factors

1. INTRODUCTION

Interest in the precast concrete (PC) construction method, in which the PC components are produced in factories and assembled on-site, has been increasing due to the aging of construction workers and the lack of skilled workers [1].

The PC construction process consists of i) PC component design, ii) factory production of PC components, iii) transportation of PC components from the factory to the site, and iv) installation of PC components on-site. The on-site PC field manager submits shipment request forms to the factory one to three days before the PC component installation, comprehensively considering the installation sequence of the PC components, the installation status of the PC components, and the availability of open storage yards. The shipment request form is a document requesting

transportation of necessary PC components, including information such as construction site, shipment request date, number/quantify/unit weight of the PC component, requested time, and installation area at the site. The production manager at the factory manages the production and storage of the PC components and reviews the shipment request forms. In addition, the production manager checks whether the PC components are produced and selects a trailer to load the PC components. The transportation manager loads the PC components on the trailer to prevent any damage in consideration of the installation sequence of the PC components and weight, then transports them from the factory to the site by the requested time on the shipment request forms. The on-site PC field manager inspects the PC components brought to the site and manages to install the PC components according to the PC component installation plan.[1] Specifically, this study examines the stage of iv) on-site installation of PC components.

When writing a shipment request form, considerations include the installation order of PC components, production status, installation status, open storage yard, interference with other processes, and crane specifications. Preparing the shipment request form with multiple considerations is complex, time-consuming, and error-prone. The time it takes to install PC components varies depending on the site conditions (unloading location, open storage yard, installation location, etc.), PC component conditions (type, size, weight, installation direction, deformity, etc.), weather conditions (temperature, wind speed, fog, snow, rain, etc.), equipment conditions (crane specifications, location, movement route, etc.), and labor conditions (the number of teams, team member composition, the number of team members, the skill level of the workers, etc.). Nevertheless, according to an interview with PC field managers, most PC field managers prepare a shipment request form with a low Level of Detail (LoD) by considering the number of PC components that can be installed per day calculated based on the average time required for installation of each PC component type. This is because the PC field manager writes the shipment request form based on his or her experience and intuition without utilizing a separate tool for preparing the shipment request form.

Errors in the shipment request form[2] cause standby or waste of resources (trailer, worker, crane), or early end of work and overtime work, resulting in increased construction cost and rework such as modification of PC component installation plan. In order to prevent this problem, a PC component installation simulation is required based on the shipment request form.

Yan-Ping (2021) greatly improved Look-ahead Schedule (LAS) performance by increasing the LoD of activity duration data for PC construction, which, in turn, increases the next-day look-ahead mean likelihood and decreases the next-day look-ahead mean absolute error and the next-day look-ahead mean cost of errors. By doing so, it was confirmed that an increased LoD can prevent increasing construction costs and delays due to scheduling errors. However, this is limited to the activity using cranes and has a limitation in that it takes a long time to plan the LAS by increasing the LoD on-site.

Garcia-Lopez (2017) developed an Activity-Flow Model (AFM) that helps field managers actively manage on-site work by officially representing, measuring, and tracking activity and flow. However, this study was conducted for the Reinforced Concrete (RC) construction method and has limitations in that it takes a significant amount of time to apply the AFM to new projects.

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[1] The PC construction process has been reconstructed in reference to [2] and [3].

[2] Errors in the shipment request form means ordering the wrong part (i.e., re-ordering a PC component that has already been installed) or inaccurately planning the request time for a PC component.

This study aims to identify factors influencing the operability of shipment request forms for PC construction.

2. Method

In this study, the PC components were limited to columns, walls, beams, and slabs. Installation, movement, and dismantlement of cranes were not considered. It is assumed that the PC components brought into the site are installed directly from the trailer without being loaded into an open storage yard. Factors influencing fluctuations in the construction period were limited to i) initiation of activity, ii) adding/deleting activity, and iii) the increase or decrease of activity execution time.

The research process is as follows:

First, the activity of PC construction was derived through an analysis of 15 contract documents and construction pictures at a site where the PC construction method was applied in South Korea, in addition to conducting a literature review. Activities with little time consumption or no flow[3] change were deleted, and similar activities were merged.

Second, with the same method, this study derived factors influencing the initiation of activity, factors influencing the adding/deleting activity, factors affecting the increase or decrease of activity execution time, and factors affecting the operability of shipment request forms comprehensively. These factors were reviewed by field managers who have worked at construction sites for more than 10 years and experienced PC construction to examine that each factor was properly deduced. Based on the review, factors that influence the order of PC components installation were deleted among the factors derived.

Finally, future research directions for simulating the installation of the PC components based on the shipment request forms were presented.

3. Influencing Factors to Operability

3.1. Factors Influencing the Initiation of Activity

Assuming that the execution time of activities is the same, a change in the start time of activity leads to changes in the end time. Therefore, the initiation of activity affects the operability of the shipment request forms. At this time, the factor influencing the beginning of the activity is the flow and variability factors.[4] According to the AFM, the activity begins when the prior process of activity is completed and all flows are satisfied [5].

The flow of each PC construction activity was derived through an analysis of contract documents and construction pictures and reviewed relevant literature. Among AFM's seven flows, only labor, equipment, and materials, which can be identified as activity without additional information on the project, were summarized. The definitions and examples of the three flows are as follow:

- Labor: Labor is the occupation of a worker performing a task. Labor was sorted by adding PC workers who install PC components and signalmen to occupations needed

[3] Construction flows are inputs that activities need to be executed efficiently. The flow can be classified into seven type (i. e., Labor, Equipment, Workspace, materials, Precedence, Information, and External flows) [5].

[4] Variability factors are external shocks to the project that are outside of the control or the field managers(i. e., Weather, Labor Strikes, and equipment breakdowns) [5].

for sites to which the PC construction method is applied among occupations in "the Construction Labor Wage Survey for the second half of 2021 released" by the Construction Association of Korea [6]. In this paper, labor includes General workers, Scaffolders, Formwork carpenters, Steel benders, Concrete workers, Plumbers, Construction machinery drivers, and Engineers related communication, and Electrical engineers.

- Equipment: Equipment is the instruments used to perform the activity. In this paper, equipment is defined as an instrument that uses power and is operated by humans. Equipment in this paper includes cranes, mobile elevated work platforms, ready-mixed concrete trucks, and concrete pump cars.
- Materials: Materials are resources inside and outside the site required to perform the task, which include raw materials or assembled items. In this paper, materials include light wave rangefinders, transits, ink pots, drills, sealant guns, epoxy, PC components, prop supports, non-shrink mortars, etc.

For example, the 'Anchor boring' activity begins when the preceding task, Marking activity, is completed, and formwork carpenter, general worker, and drill are satisfied.

Table 1. Activity & Flow of PC construction_related the PC Wall component installation

No.	Activity	Labor	Equipment	Materials
1	Marking	Formwork carpenter, General worker	-	Light wave rangefinder, Transits, Ink pot
2	Anchor boring	Formwork carpenter, General worker	-	Drill
3	Cleaning inside the hole	General worker	-	Air pump
4	Injecting epoxy	Formwork carpenter, General worker	-	Sealant gun, Epoxy
5	Embedding of anchor	Formwork carpenter, General worker	-	Anchor
6	Epoxy curing	General worker	-	Water
7	Pull-out test	Formwork carpenter, General worker	-	Pull-out tester
8	Floor level measurement	Formwork carpenter, General worker	-	Transit
9	Installing liner plate or steel shim	Formwork carpenter, General worker	-	Liner plate or steel shim
10	PC wall component lifting and installation	PC worker, crane signalman, construction machinery driver		PC wall component
11	Checking the verticality of	PC worker	-	Transit

	the PC wall component			
12	Prop support installation hole drilling	PC worker	-	Drill
13	Installing prop spport	Scaffolder	-	Prop spport
14	Grouting at the joint	Concrete worker	-	Non-shrink mortar
15	Caulking	Concrete worker	-	Epoxy, Silicon gun
16	Curing	General worker	-	Water
17	Cutting reinforcing bar	Steel bender	-	Bar cutter
18	Dismantling the pop support	Scaffolder	-	Hammer
19	Grouting to the Prop Support installation hole	PC worker	-	Non-shrink mortar

3.2. Factors Influencing Adding/Deleting Activity

Assuming that the execution time of each activity is the same, if the number of activities increases, the construction time will increase. On the other hand, if the number of activities decreases, the construction time will decrease. Therefore, adding/deleting activity affects the operability of the shipment request forms. In this case, the factor influencing the adding/deleting activity is the features of the PC components.

The features of the PC components such as columns, walls, beams, and slabs that affect the adding/deleting activity were derived through an analysis of contract documents and construction pictures and reviewed relevant literature. The description of the features of each PC component and the activity to be added or deleted are as follows:

3.2.1. Column

- Anchor construction period: The anchor construction period is divided into “Pre-construction” and “Post-construction”. Pre-construction is to embed an anchor when placing the foundations or slab concrete. Post-construction is to embed an anchor after curing the foundation or slab. In the case of pre-construction of the anchor, activities on “anchor boring, cleaning inside the hole, injecting epoxy, embedding anchor, and curing epoxy” are deleted. In the case of post-construction of the anchor, no activity is deleted.
- Hollowed column: Whether the column is hollowed is divided into “Hollow” and “Solid”. A hollow is the presence of empty space in a column. Solid means that there is no empty space in a column. For hollowed columns, activities on “installing a form at the bottom of the column, placing non-shrink mortar at the bottom of the column, and dismantling the form at the bottom of the column” are deleted. For solid columns,

activities on “installing square lumber, constructing polyurethane foam and rubber stopper, injecting non-shrink mortar, removing square lumber and rubber stopper” are deleted.

- Prop Support installation hole: Whether the prop support installation hole is divided into “Installation hole” or the “No installation hole”. The presence of an installation hole means that there is a hole for installing prop support on the side of the PC column component. The no installation hole indicates that there is no hole for installing prop support on the side of the PC column component. If there is an installation hole, activity on the “prop support installation hole drilling” is deleted. If there is no installation hole, no activity is deleted.

3.2.2. Wall

- Reinforcing bars in the lower component: Whether reinforcing bars in the lower component (foundation or slab) is divided into “reinforcing bars in the lower component” and “no reinforcing bars in the lower component”. The presence of the reinforcing bars in the lower component means that there is a reinforcing bar for ensuring integrity with the PC wall component in the lower component of the PC wall component. The “no reinforcing bar in the lower component” indicates that there is no reinforcing bar for ensuring integrity with the PC wall component in the lower component of the PC wall component. If there is a reinforcing bar in the lower component, activities on “anchor drilling, cleaning inside the hole, injecting epoxy, and anchor embedding” are deleted. If there is no reinforcing bar in the lower component, no activity is deleted.
- Reinforcing bar in the opening: Whether reinforcing bars in the opening (door or window) is divided into “reinforcing bar in the opening” and “no reinforcing bar in the opening”. The reinforcing bar in the opening means that there is a reinforcing bar in the opening to prevent deformation of the PC wall component with the opening. The no reinforcing bar in the opening indicates that there is no reinforcing bar in the opening to prevent deformation of the opening despite the presence of the opening in the PC wall component. If there is a reinforcing bar in the opening, no activity is deleted. If there is no reinforcing bar in the opening, the activity on “Cutting reinforcing bars” is deleted.
- Prop Support installation hole: Whether prop support installation hole is divided into “Installation hole” and “No installation hole”. The presence of an installation hole means that there is a hole for installing prop support on the side of the PC wall component. The no installation hole indicates that there is no hole for installing prop support on the side of the PC wall component. If there is an installation hole, activity on the “Prop support installation hole drilling” is deleted. If there is no installation hole, no activity is deleted.

3.2.3. Beam

- Location: The location is divided into an “end part” and a “central part”. The end part is where the PC beam component is located outside the building. The central part is where the PC beam component is located inside the building. For the end part, there is no activity to delete. In the case of the central part, the activity on the “end plate construction” is deleted.

3.2.4. Slab

- Location: The location is divided into an “end part” and a “central part”. The end part is where the PC slab component is located outside the building. The central part is where the PC slab component is located inside the building. In the case of the end part, there is no activity to delete. In the case of the central part, the activity on the “end plate construction” is deleted.

3.3. Factors Influencing the Increase/Decrease in Activity Execution Time

Assuming that the activity execution begins at the same time, the end time of the activity varies as the activity execution time increase or decreases. Therefore, the increase or decrease in the activity execution time affects the operability of the shipment request forms. In this case, the factors that influence the increase or decrease of the activity execution time are the condition of PC component, unloading location, installation location, input equipment and labor, the number of anchors of vertical PC components (columns, walls), types of epoxy and non-shrinkage mortar, the number of support installations, weather (temperature, wind speed, fog, snow, rain), etc. For example, the time for the activity on “anchor boring” can vary. In the case of the number of anchors of the vertical PC component, assuming that one anchor takes one minute to be drilled, a column with one anchor takes one minute to drill the anchor while a column with four anchors takes four minutes to drill the anchor.

3.4. Compound Factors

The compound factors are factors that affect the “initiation of activity” and “increase or decrease of activity execution time”, which then influence the “initiation of activity” before starting activity and “increase or decrease of activity execution time” during activity. Compound factors include weather (temperature, wind speed, fog, snow, rain, etc.), strikes, and accidents. For example, if it rains or snows before the start of an activity, this is a factor that affects the initiation of the activity, but if it rains or snows during the activity, it is a factor that affects an increase or decrease in the time of activity execution.

4. Conclusions and Future Work

Despite the increasing interest in the PC construction method, PC field managers are still preparing a low LoD shipment request based on their experience and intuition without utilizing a separate tool. Errors in the shipment request form cause standbys in resources, waste of resources (trailers, workers, cranes), or early end of work and overtime work, which can lead to an increase in construction cost and rework such as modification of PC component installation plan. To prevent this issue, a PC component installation simulation should be conducted based on the shipment request form.

In this study, in order to identify the factors influencing the operability of the PC construction shipment request forms, factors affecting the initiation of the activity, addition/deletion of activity, and the increase or decrease of execution times were derived. The factor that influences the beginning of activity is flow. The factor influencing the adding/deleting activity is the features of the PC components. Factors that affect the increase or decrease of activity execution time include the condition of PC components, unloading location, installation location, the input of equipment and labor, number of anchors, number of supports, and weather. Finally, compound factors that affect the initiation of activity or the increase or decrease in the execution time of activity are weather, strikes, and accidents.

This study is significant in that it identified factors influencing the operability of the shipment request form. In existing studies, only factors affecting the start of activity were considered.

Conversely, in this study, factors affecting the initiation of activity, addition/deletion of activity, and increase/decrease of the execution time were considered.

In the future, in order to simulate the installation of the PC components based on the shipment request forms, it is necessary to verify the activity and flow of PC construction, the features of the PC components that affect the adding/deleting activity, factors that affect the increase or decrease of activity execution time, and compound factors through focus group interviews. The execution time of each activity should be measured and the amount of materials required should be formalized. Moreover, it is necessary to verify under which conditions and how much each factor influences the increase or decrease of the activity execution time. Finally, the feature of the PC component must be formatted to be recognizable by the computer.

This study is expected to help field managers calculate the construction period on the requested date before submitting the shipment request forms by identifying the factors influencing the operability of the shipment request forms. Also, this study contributes to off-site construction theory by defining the PC component installation activity and their resources, which can be used in systemizing and automating schedules in tandem with AFM.

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REFERENCES

[1] E. B. Jeong, C. S. Lee, C. W. Koo, T. W. Kim, “A Study on the Simulation Method of PC Construction Schedule based on Activity-Flow Model”, Proceedings of the Autumn Annual Conference of AIK, Yeosu, Korea, pp. 503-504, 2021.

[2] J. Y. Jang, K. W. Cho, C. W. Koo, C. S. Lee, T. W. Kim, “Importance and Performance Analysis on Factors of PC Component Allocation and Loading Planning”, Korean Journal of Construction Engineering and Management, vol. 22, no. 2, pp. 53-62, 2021.

[3] S. Y. Hwang, J. J. Kim, J. R. Sohn, C. B. Sohn, “Optimal Management of Precast Concrete Panels in Apartment Construction”, JOURNAL-ARCHITECTURAL INSTITUTE OF KOREA, vol. 13, pp. 417-428, 1997.

[4] Yan-Ping Wang, “How Level of Detail of Activity Duration Data Influences Look-Ahead Schedule Performance in Prefabricated Construction” Doctoral Dissertation, Stanford University, 2021.

[5] Garcia-Lopez, N. P., “An Activity and flow-based Construction Model for Managing on-site Work”, Doctoral Dissertation, Stanford University, 2017.

[6] Construction Association of Korea, “The Construction Labor Wage Survey for the second half of 2021 released”, 2021.