SIMULATION METHOD OF CONSTRUCTION HOIST OPERATING PLAN FOR HIGH RISE BUILDINGS CONSIDERING LIFTING HEIGHTS AND LOADS

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Abstract

Lifting indicates vertical transfer of construction resources. In high-rise building, efficient plan and management on lifting of resources are essential because of enormous impact on schedule, and amount of resources and data. In particular, a hoist—one of main lifting equipment for workers and construction materials—may have direct influence on overall project schedule depending on its number, location and operation method. To ensure efficient construction, it is critical to have an optimal hoist operating plan. Engineers depend on various empirical methods, which have been optimized through numerous feedbacks from construction projects. Therefore, it is necessary to optimize hoist plan and management based on both engineers' experiences and simulation based on actual data on lifting load and height. This paper describes a simulation method to provide data to an experienced engineer for accurate decision-making.

KEYWORDS: Lifting, Simulation, High-rise Building, Hoist, Lift Car, Lifting Management

INTRODUCTION

In a construction project, lifting indicates vertical transfer of construction resources. A high-rise building project has special needs as a limited number of pieces of lifting equipment should move large amount of materials up to a working area on high floors (Ahn, 2004). Also, as a building becomes higher, amount of materials and overall management data on work process and cost increase exponentially (Cho et al., 2009). Thus, efficient plan and management on lifting of resources are essential. In particular, a hoist—one of main lifting equipment for workers and construction materials—may have direct influence on overall project schedule depending on its number, location and operation method. To ensure efficient construction, it is critical to have an optimal hoist operating plan. For this purpose, engineers depend on various empirical methods, which have been optimized through numerous feedbacks from construction projects. However, since the empirical methods are based on estimate (assumption) for lifting load and height—which are critical elements of hoist operating plan—it is inaccurate and is hard to promptly respond to different types of projects and changes in construction conditions. Therefore, it is necessary to optimize hoist plan and management based on both engineers' experiences and simulation based on actual data on lifting load and height. This paper describes a simulation method to provide data to an experienced engineer for accurate decision-making.

RESEARCH TRENDS

Al-Hussein developed an optimization algorithm for selection and arrangement of a mobile crane (Al-Hussein et al., 2005), and 3D visualization and simulation system for a tower crane (Al-Hussein, 2006). R. Sacks developed an automated lifting equipment monitoring system of lifting equipment (Sacks et al., 2005). Jang conducted research on optimization for floor-level construction material layout using genetic Algorithm (Jang et al., 2006), and Tantisevi undertook a study on simulation-based identification of possible locations for mobile crane (Tantisevi et al., 2008). Many of the previous studies focused on tower crane and mobile crane, and in comparison, only a few studies have been undertaken on planning and management of hoist lifting.

In Korea, the proportion of interior work in a super high-rise building is substantial, and thus lifting is extensively used. Several studies have been undertaken on the subject. However, they applied uniform calculation method and quantity estimate for materials to calculate lifting cycle and number of required hoists. Such method shows discrepancy with actual construction site conditions, and leads to prolonged waiting time for construction workers at peak time (Park et al., 2001). It is because the calculation formula adopted simplistic assumptions—consistent input of materials during working hours, fixed cycle time and number of people in a lift, and fixed operating rate of a lift. Previous studies on planning for construction lifts were largely based on such simplified formula to analyze economic benefit and efficiency. In terms of simulation-based research, Ahn (Ahn, 2004) applied discrete-event simulation to a vertical movement process to show that a lifting plan can be made that reflects conditions and needs of a construction site. However, the study lacked considerations for movement of materials, waiting time to use a lift, and probable flexibility of a construction-use lift. As a result, the study outcome could not be fully utilized to calculate required number of lifts, their specifications, and establish operating plan for construction management.

RESEARCH CONCEPT

This research is a part of a mega research project to develop efficient design, construction and material technologies in a super high-rise building project. As shown in Figure 1, this research attempts to develop a hybrid lifting planning and management system that combine optimized experiences of engineers and benefits of a simulation method. The concept of the system is to help an engineer to make best use of experiences and know-how in establishing lifting plan and management based on a simulation method. Since the system integrated with schedule information including quantity, it can have accurate calculation basis unlike estimate-based calculation of lifting time and number of lifts. Also, the system takes into account safety factor, which can be more reasonable than the existing method that considers safety factor after yielding estimates (assumptions). The paper focuses on the resource library for lifting simulation and calculation of lifting time, as the gray marked areas in Figure 1 show.

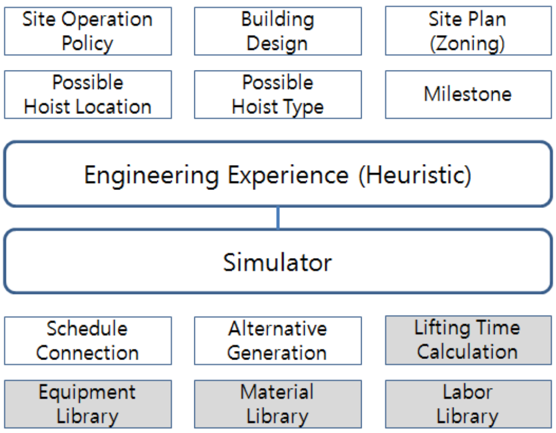


Figure 1: System Concept

SIMULATION RESOURCE LIBRARY

To carry out a lifting simulation, a library is needed that contains attributes of lifting equipment, workers and materials. This is different from resource database used in general project management. In cost and resource management, amounts and unit prices of resources are critical. However, in lifting simulation, unit price is not a significant factor. More than that, the simulation requires physical properties of a lift—speed, size, weight—and operation data such as delivery time, rental cost and loading/unloading time and so on. Noting this, a lifting simulation resource library was established with a structure illustrated in Figure 2. This library needs to be linked to the overall project resource database with a unique ID code.

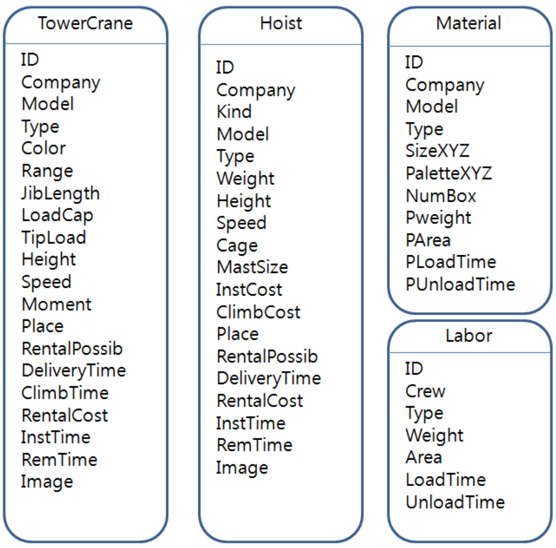


Figure 2: E-R Diagram of Simulation Resource Library

SIMULATION METHOD

Method

Basic purpose of this lifting simulation is to calculate hoist operation cycle time according to lifting load. To do so, a method was defined to calculate cycle time based on physical calculation. Basic model of this calculation method is described in Figure 3.

H : Base Floor Heights

H_b : Heights from 1st to typical floor

h_1 : acceleration distance

h_2 : reduction distance

s_1 : acceleration time

s_2 : reduction time

n : total number of stopping floors

m : total number of passing floors

v : constant velocity

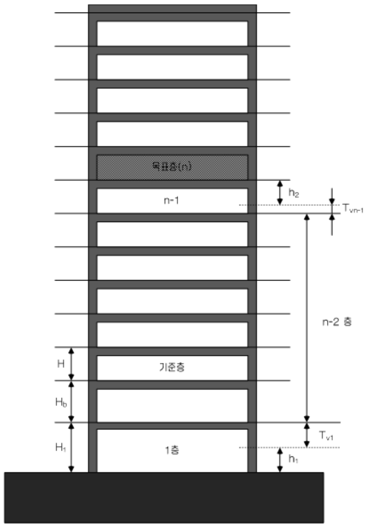


Figure 3: Basic Model for Hoist Cycle Time Caculation

As demonstrated in previous studies, cycle time for lifting (T) was defined as follow Formula 1 (Cho, Kwon et al., 2009). T_m indicates lifting time of a hoist, and T_l means loading/unloading time of resources such as workers and construction materials.

$$T = T_m + T_l \qquad \textbf{Formula 1}$$

In addition to the Formula 1, the research took into account acceleration and deceleration of a hoist, which vary by hoist types. They must be considered in super high-rise buildings with different heights and number of floors. Thus, T_m in Formula 1 can be calculated by adding T_{os} (lifting time at operation speed), constant of S_1 (acceleration time) on the first floor, and constant of S_2 (reduction time) before reaching the target floor (n-1 floor). Formula 2 can be described as:

$$T_m = T_{as} + S_1 + S_2 \qquad \textbf{Formula 2}$$

Total accelerated speed lifting time T_{os} can be calculated by adding lifting time after acceleration is completed on the first floor (T_{v1}), lifting time before reduction is started ($T_{v(n-1)}$) and lifting time of passing floors at operation (accelerated) speed (T_v). This can be shown as in Formula 3 and 4.

$$T_{os} = T_{v1} + T_{v(n-1)} + T_v \qquad \textbf{Formula 3}$$

$$T_{v1} = \frac{H_1 - h_1}{V}, T_{v(n-1)} = \frac{H_{n-1} - h_2}{V}, T_v = \frac{\sum_{i=2}^{i=n-2} Hi}{V}$$ **Formula 4**

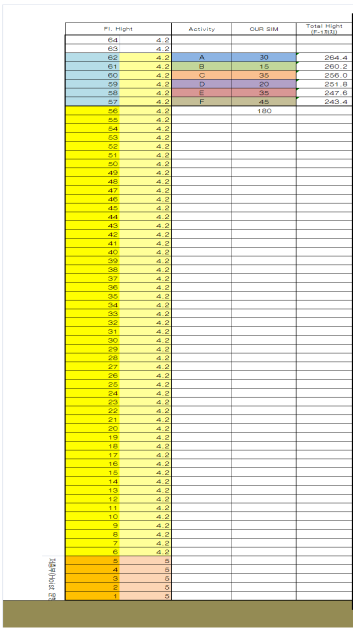
Loading/Unloading time (T_l) can be defined as follows. T_{do} means hoist door open time, T_{dc} means hoist door close time, and T_{lo} indicates time taken to load or unload resources.

$$T_l = T_{do} + T_{dc} + T_{lo}$$ **Formula 5**

Simulation

A lifting model was set up to verify the proposed calculation method, and a simulation was carried out. The simulation variables included total lifting load, hoist capacity, number of target floors, loading/unloading time, door open/close time, hoist speed and lifting priority. Table 1 lists specific values.

Table 1: Simulation Conditions



Total Lifting Load	180 unit
Hoist Capacity	20 unit
Number of Target Floors	6
Loading/Unloading Time per Load Unit	0.05 min
Door Open/Close Time	0.1 min
Hoist Speed	100 m/min
Number of Hoist	1

Lifting Priority	Activity	Load	Target Floor
1	A	30	62
2	B	15	61
3	C	35	60
4	D	20	59
5	E	35	58
6	F	45	57
Total Load		180	

Figure 3 and Table 2 illustrate result of the simulation. In Figure 3, the left column shows simulation result of the process proposed in this research, while the right column shows result of as-is lifting plan. The as-is method depends on rough estimate for general projects, and does not consider various scenarios according to work processes, different amount of materials or engineers' experiences. In comparison, the proposed method takes these elements into account, and performs calculation in consideration of various lifting scenarios. Although both simulation methods concluded that the process requires 9 times of lifting, the proposed process calculates optimal combination of lifting activities, which enabled to reduce the lifting time from 73.8 minutes to 66.9 minutes.

Figure 4: Simulation Process

Table 2: Simulation Results

	Simulation								
Lifting Cycle	1	2	3	4	5	6	7	8	9
Unloading Time	1.2	1.4	1.4	1.2	1.2	1.4	1.2	1.2	1.2
Lifting up Time	2.7	2.7	2.6	2.6	2.6	2.5	2.5	2.5	2.5
Lifting Down Time	2.7	2.7	2.6	2.6	2.6	2.5	2.5	2.5	2.5
Loading Time	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Total Time per cycle	7.6	7.8	7.7	7.4	7.3	7.4	7.2	7.2	7.2
Total Lifting Time	66.8								
	As-is Process								
Lifting Cycle	1	2	3	4	5	6	7	8	9
Unloading Time	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Lifting up Time	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Lifting Down Time	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Loading Time	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Total Time per cycle	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2
Total Lifting Time	73.8								

CONCLUSIONS

This research provides basic elements to establish a optimized hoist lifting planning and management system for a super high-rise building project. The basic concept is to combine engineers' experiences with a simulation method to perform optimal lifting planning and management. The research proposed how to calculate lifting cycle time according to varying lifting heights and loads. To verify its feasibility, the research compared existing method and proposed method in calculating lifting cycle time. The existing method relies on rough estimate (assumption) for a general construction project, and does not reflect changes in work processes, quantity of materials and scenarios based on engineers' experiences. However, the new method proposed in the research considers all these elements in calculation, and provides various alternatives as a result. By examining various scenarios, engineer might select an optimal scenario based on calculating accurate lifting cycle time.

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