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Development of a Masonry Lift Selecting Simulation

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Abstract

Decision making to select a lift in high-rise construction is dependent on experiences and intuitions of experts. This generates mistakes in making decisions. Therefore, the systematic system to select a lift in every project is required for performing accurate projects. In this study, the site information was collected to develop a simulation for selecting a lift followed by choosing case sites. Based on this information, basic values were calculated to apply to the simulation. System rental and labor costs were estimated from this application of calculated data to the simulation and adequate lift speed and its number were selected by estimating total construction costs. The change of construction period by lift speeds were confirmed by calculations of data to apply to the simulation. It was validated that the faster lift speeds the shorter construction periods. Equipment rental and labor costs were estimated to calculate construction costs by lift speeds. It was little affected because a value of equipment rental equipment rental was considerably lower than a value of labor costs. And the change of total construction costs was similar with the graph. Conclusively, it was confirmed that total construction cost was decreased by an increased speed of technician at the same section and that the cheapest section was 70m/min. This study suggested a systematic simulation for selecting a lift so that will expect to be applied more objectively and effectively at construction sites. However, this study is a basic research to develop the simulation due to limited applications of sites and types. Therefore, it is necessary to identify an efficiency of simulation through various site applications in the future.

Keywords: Construction lifting equipment, Lifting speed, Lifting plan, Simulation model, Masonry.

1. Introduction

The number of high-rise building in Korea is gradually growing with advanced construction technology(Kang et al., 1996). Prior to evaluating economic efficiency of building itself, high-rise building represents a landmark showing national economic power(Cho and Cho, 2009). According to Ministry of Land, Infrastructure and Transport of Korea, the number of high-rise buildings were approximately increased more than double from 1,661 in 2016 to 3,165 in 2020(MOLIT, 2021). As movements of heavy materials are complicated and popular due to increasing high-rise building, a lift should be used to supply construction resources to sites in high levels(Shin et al., 2017; Jung et al., 2017; Zhang and Pan, 2020; Cho et al., 2010). As a main hypothetical plan which is in the basis of entire construction plan, the lifting plan in high-rise constructions has directly influenced to construction periods, construction costs and safety managements(Kim et al., 2002; Lee and Han, 2008). So a planned management of lift is a key element for successful project(Shin et al., 2016). The planned work can be stopped without consecutive supply of required resources due to inadequate lifting plan and the construction can be considerably delayed(Park et al., 2013; Kim and Han, 2008).

This depends on the suitability of lift planning in constructions. Especially, unsystematic lift selections couldn't choose adequate lift in every project. Current decision making for selecting lift at construction sites is dependent on experiences and intuitions of experts based on different standards of each company(Cho et al., 2011). But this is inadequate and has difficulty responding immediately to changes of other projects and cons truction circumstances because of based on rough estimates of experts. In addition, it is feasible to generate mistakes for decision making(Ahn and Kim, 2001; Lee et al., 2014). Therefore, a systematic system is necessary to establish appropriate management plans on each project to execute effective projects. This study describes how to develop the simulation for selecting a lift with appropriate performance on every project of high-rise building construction.

In this study, a lift selecting simulation is progressed by choosing mason construction that is one of heavy lifting load construction and uses small materials such as tiles or bricks. For this, a simulation model of 40-story construction project is built up with a field investigation of 47-story construction. The relationship between equipment rental and labor cost is analyzed by lifting capacity of lifts. They are categorized by low, medium and high speeds. Generally, the loading weight and cage size are increased as fast as lift speed. In other words, it means that lifting capacity could be different with the lift speed. Therefore, this study estimates the most adequate number of lists followed by calculating mason construction period and costs by lift speeds. As shown in Figure 1, it has four steps processed. A status of current construction lifts were investigated and field information was collected in this study. In addition, it was confirmed that the project period and labor productivity according to the speed and number of lifts. The project period was simulated as a dependent variable. Based on this information, the adequate lift number and speed could be estimated after calculating basic value for simulations and applying these to the simulation. And then it finally suggested the optimum simulation.

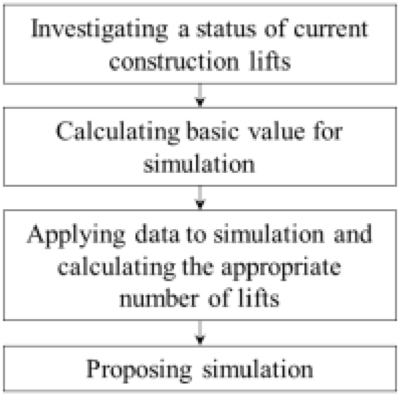

Figure 1. Study flow

2. Preliminary study

If not reflected with field conditions, the selection plan of lifting equipments could be a considerable effect on success or failure of a project due to high-rise project characteristics having complicated construction fields and influenced external factors(Cho et al., 2011). It is essential to figure out field status and execute systematic lifting management for establishing a lifting plan. According to these necessities, many studies have recently developed calculation models, algorisms and simulations for adequate lifting plan.

Shin and Kang(2017) mentioned a need of lift operation plan in the construction step through reflecting effective factors to lifting plan(Shin and Kang, 2017). So he developed an analysis system of optimum lift operation that can execute analysis in real-time. And he collected information of operation history by developing ELIS (Embedded Lift Information System) which analyzes operating pattern data to enhance lift operating efficiency. The optimum vertical operating zone was set up on the basis of 4-day cycle lift operating pattern using a tact method to analyze expected operations. In addition, the effect of reducing users' waiting time on the lift operation plan was verified through the simulation. Cho et al. (2011) developed an algorism to estimate the lifting plan time considering acceleration and deceleration of lift(Cho et al., 2011). He suggested an algorism that can derive average acceleration/deceleration according to lift speeds and sizes and can calculate physical movements of lifts. The efficiency of this algorism was verified by comparing with current lift efficiency prediction. Finally he figured out an error rate for predicting its operation time by completing the test for lift operation time after its application to the field. Kim and Han(2008) suggested an estimation method of accurate lifting number instead of experiences and intuitions of experts and presented a plan to verify if estimated lifting number is correct or not(Kim and Han, 2008). He specifically indicated a process that can calculate the lift number for 1 day lifting weight by figuring out a time required for lifting laborers and materials. He executed the simulation by setting variable elements discretionally such as lift loading-unloading time, waiting time and material lifting amounts but couldn't verify for this. Lee et al. (2014) suggested an integrated model of lift plan and management for high-rise building finishing works to make reasonable decisions(Lee et al., 2014). By presenting lifting progress schedule, lifting TACT and schedule that are connected to the accurate lift plan established by considering field lifting loads at initial construction, he developed a model to utilize as an actual lifting management tool for workers. Shin and Kang(2010) proposed a model that can establish lifting equipment plan and its installation plan of construction lifts in high-rise building constructions(Shin and Kang, 2010). He used a discrete event simulation which is a system to track a change of system status variables only at the point of time distinguished. And he tried to calculate appropriate equipments and installation period through various combinations. However, he couldn't quantify different data from every project so that faced a limit to derive an objective mode without considering additional factors including material lifting plan. In addition, Shin(2011) suggested a lifting plan system of construction lifts to solve difficulties of decision making by environments of construction sites(Shin, 2011). He finally realized a visual system to use not only in early stage but in construction process by easily input and output of effective factors which have to consider lifting plan steps.

3. Simulation for selecting the lift speed

3.1. *Construction lift status*

The most popular lifts in Korea are currently 'KJL' and 'ALIMAK'. Table 1 shows speed, capacity and cage size by each type. A construction lift is classified into low, medium and high speeds for all types. Three lift speeds are defined in this study as follows; a low speed in 0~55m/min, a medium speed in 0~70m/min and a high speed in 0~100m/min.

Table 1. Performance of lifts currently used

	Model	Speed(m/min)	Weight(kg)	Cage size(m^3)
High speed	KJL/2545S	100	2500	4.5*1.5*2.9
	ALIMAK SC650FC-S	100	2400	5.0*1.5*2.8
Medium speed	KJLC-2040S	70	2000	4.0*1.5*2.9
	ALIMAK CN 25/46 FC	65	2200	4.6*1.5*2.3
Slow speed	KJL-1232S	45	1200	3.2*1.2*2.6
	ALIMAK SC450	54	2000	3.2*1.4*2.1

3.2. *Field investigation*

The apartment site of Company H located at Sejong, Korea was used for executing the simulation. For generalized calculations, the highest building in this site was targeted to investigate total area of ground floor, the number of floors, hoist installation height, mason construction period and used lift performance. These investigations are listed in Table 2 and were calculated by converted to 20 days assuming that one month is the same with four weeks of five days working a week. In case of used lift performance, its speeds for high, medium and low were 100m/min, 65m/min and 38m/min respectively. In addition, Section 3.3 describes an investigation of lift performance used in fields and current lifting plan calculation formula.

Table 2. Performance of lifts currently used

	Contents	
Total floor area(m^2)	15,160	
The number of floors	48	
Hoist installation height(m)	196	
Mason work period(day)	360	
Lift performance (Speed/Weight/Cage size)	High speed	100 / 2500 / 4.5*1.5*2.9
	Medium speed	65 / 2000 / 4.6*1.5*2.3
	Slow speed	38 / 1200 / 3.0*1.2*2.6

3.3. *Calculation of basic value for simulation*

As shown in Table 3, a lifting plan calculation formula used in fields was investigated to calculate lift number for one building of apartment. According to the formula, the number of 1 day lifting obtains in the maximum value compared to lift installation period. And then actual number is predicted by adjusting 30% for mason lifting and 10% for laborer lifting. In addition, a mason lifting adjusts about 30% by considering a speed of material loading-unloading time. Total required material amounts, total average material amounts and a required material amount per unit area are calculated for the simulation.

Table 3. Lifting plan calculation formula of case sites

Criteria	Contents	Results	Unit	Calculation method
Mason lifting criteria	The number of lifting per unit area(time/m^2)	1.00	time/m^2	Performance data base
	The number of lifting per total area	15,160.00	time	The floor area of ground floor * The number of lifting per unit area
	Necessary number of lifting per a day	28.07	time	(The floor area of ground floor * The number of lifting per unit area) / The number of days of finishing work
	Average running height(m)	117.60	m	The height of the building * (1/2) * 1.2
	Lifting cycle(min/times)	10.60	min/time	(The average driving height / (The average driving speed*0.7) * 2(Round trip) + 5(Time to go up and down)
	Possible number of lifting per a day	35.66	time	((The lift installation period*30) / lifting time) * 0.7
	The number of lift(A)	0.79	EA	The number of lifting times required one day / The number of possible lifting times required one day

Human lifting criteria	Maximum output people at peak time	216.57	people	The floor area of ground floor / 0.7
	Maximum number of personnel transportation	78.75	time	Maximum output during peak time / Maximum number of passengers) * 4
	Possible number of lifting per a day	50.63	time	The lift installation period * 30) / (lifting time - 1)) * 0.9
	The number of lift(B)	1.56	time	Maximum number of people transported/ The number of possible lifting times required one day
Total	The total number of lift (A+B)	2.35	EA	The number of lift (A+B)

Through construction information of Company H, we investigated types and number of rooms and required material amounts by room types for every floor and building. Because of different floors in each building, 7 buildings with different floors were selected to calculate material amounts in each floor. 4 buildings were chosen in Part A and 3 buildings in Part B. Any floors including public facilities were excluded on this calculation for accurate investigation. And then we calculated the required material amount for each building and the average material amount by buildings. Formula (1) explains to calculate a required material amount and formula (2) for an average material amount per floor. Table 4 indicates the results calculated by formulas.

$$\text{A required material amount} = \sum(\text{Construction capacity per unit area} \times \text{The number by type}) \quad (1)$$

$$\text{An average material amount per floor} = \frac{\text{A required material amount}}{\text{The number of floors}} \quad (2)$$

Table 4. Results of material calculation in case sites

	A-1	A-2	A-3	A-4	B-1	B-2	B-3
A required material amount	668,803	809,131	759,742	809,131	748,773	722,347	481,051
The number of floors	32	40	37	40	38	35	24
An average material amount per floor	20,900	20,228	20,534	20,228	19,705	20,638	20,044

Prior to executing a simulation, total material amount to lift in case site was calculated. Likely Table 5, an average material amount per one building was calculated by adding average material amount in floors and dividing to 7 buildings. Then we need to calculate the residential area of one floor and the buildings in this study represented two of 88m^2 and two of 99m^2 for all floors similarly. So the residential area of one floor was calculated to 366m^2. An extra 20% was added to the residential area to consider areas of corridor and core. As a result, the construction area of one floor was calculated to 439.2m^2. For the next to calculate the required material amount per unit area, it divides an average material amount per one building into the construction area of one floor. In last, construction area, number of floors, building height and total area of ground floors are needed to calculate for total required material amount to lift. This total required material amount can be obtained by a multiplication of the required material amount per unit area and total area of ground floors for all buildings. Therefore, total required material amount of case sites investigated in this study was calculated to 813,048.

3.4. ***Suggestion of simulation for selecting the lift speed***

With previously calculated basic value, the number of required lifts by lift speeds is obtained and its period of mason construction is calculated to select adequate lift in case sites. A required lift number was calculated by lift speeds. As shown in Figure 2, actual required lifts are four because of 3.71 lifts needed for the low speed (45~55m/min) and three lifts because of 2.38 lifts needed for the medium speed (56~70m/min). Because the high speed lift (71~100m/min) requires 1.71 lifts, actual required lifts are two.

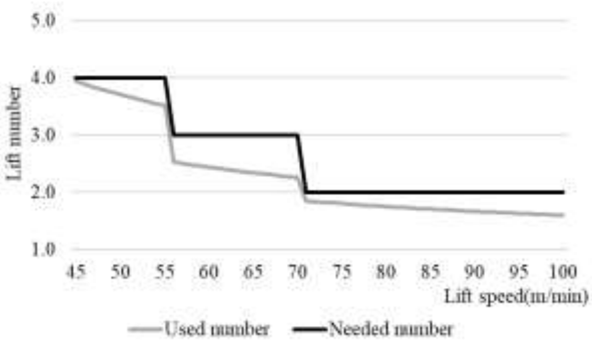

Figure 2. Average number required by lift speeds

The next is to confirm the change of construction period according to lift speed changes. Likely Table 5, the construction period was calculated by 1 day lifting number according to speed changes and each period includes the round without decimals. A period calculation was completed by assuming 1 month is the same with 4 weeks, 20 days of 5 days working a week. As the result in Figure 3, it confirmed that the faster lift speeds the shorter construction periods.

Table 5. Construction period by lift speeds

	Lift speed	One day lifting number	Average of construction period	
			Month	Day
Slow speed	45~55	36.01	16.28	325.58
Medium speed	56~70	40.36	14.52	290.46
High speed	71~100	45.94	12.77	255.36

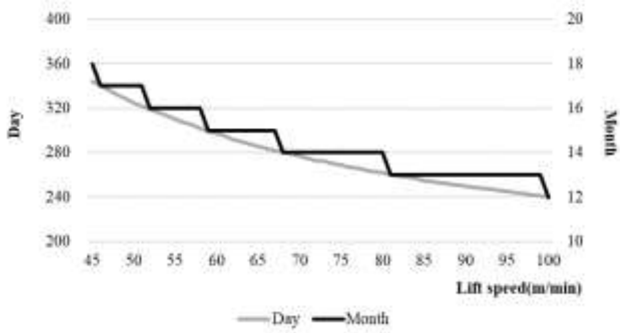

Figure 3. A change of construction period by lift speeds

An equipment rental was calculated to estimate construction costs generated by lift speeds. First of all, formula (3) represents to calculate total equipment rental by multiplying required number, construction period and equipment rental. Based on the performance data, the equipment rental by lift speeds were calculated to 631.84 USD for the low speed, 1,263.69 USD for the medium speed and 2,527.38 USD for the high speed. This cost might be varied by contract method and customers. Figure 4 indicates that the equipment rental was the lowest in 50~55m/min and the highest in 70~80m/min.

$$\begin{aligned}&\text{Total equipment rental fee}\\&= \text{Number of required lift}\\&\times \text{Construction period}\\&\times \text{Equipment rental fee}\end{aligned} \quad (3)$$

Table 6. Equipment rental fee by lift speeds

Lift speed	Average construction period(month)	Number of lift	Rental fee(USD)
45~55	16.28	4	44,213.06
56~70	14.52	65	59,481.85
71~100	12.77	38	70,320.76

Figure 4. A change of equipment rental by lift speeds

And then the required labor cost was calculated by lift speeds. The number of people for calculating the required labor cost includes experts, small carriers and operators. Based on the performance data, labor costs were calculated in 210.61 USD per day for experts and 126.37 USD per day for small carriers and operators. As indicated in formula (4) and (5), 1 day required number of experts was obtained from 1 day construction amount and calculated by dividing work amount per person. And also one day construction amount of mason expert was assumed as 1,500 per day based on the performance data. Because a consideration of mason lifting efficiency is feasible for movements on each work amount, we assumed to work as one crew consisted of one expert and one small carrier. One operator per a lift was arranged by its related law if lift speed is over than 80m/min. Table 7 shows a total labor cost according to classifying the speed and Figure 5 explains the change of total labor cost by lift speeds.

$$\begin{aligned}&\text{One day construction amount}\\&= \frac{\text{Total amount of construction materials}}{\text{Working days}}\end{aligned} \quad (4)$$

$$\begin{aligned}&\text{Required number of experts}\\&= \frac{\text{One day construction amount}}{\text{Work amount per expert}}\end{aligned} \quad (5)$$

Table 7. Total labor cost by lift speeds

	Lift speed	Average amount of work per day	Average required labor	Labor cost(USD)
Slow speed	**45~55**	2496.14	1.664	258,547.76
Medium speed	**56~70**	2797.54	1.865	230,683.82
High speed	**71~100**	3182.44	2.122	339,826.40

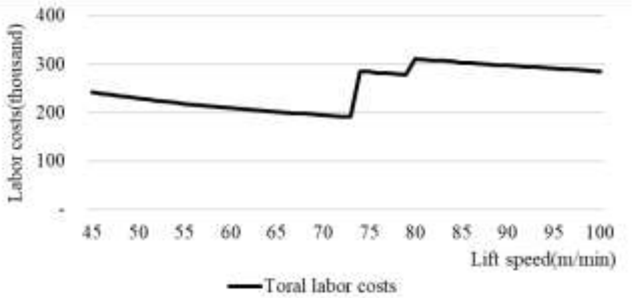

Figure 5. A change of labor cost by lift speeds

As shown in Figure 6, total construction cost was calculated by adding equipment rental and labor cost according to lift speeds. There was little impacted with lower value of equipment rental than labor cost and the overall trend of graph was similar with a graph of labor cost. In addition, we confirmed that the construction cost was obviously increased in sections of 55~56 and 70~71m/min which are experts changed. An addition of operator if over 80m/min increased labor cost as well. Conclusively, the faster lift speed the less construction cost in the same number of experts existed. Also, the lowest cost was in the speed of 70m/min.

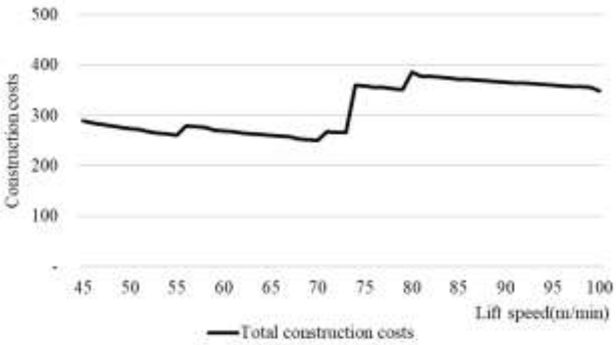

Figure 6. A change of total construction cost by lift speeds

The simulation was executed to select the lift speed including the lowest cost with actual construction field data. Figure 7 indicates three steps of simulation process. The first is to calculate for the simulation. The required material amount per unit area should be calculated after obtaining average material amount per floor. And then the required material amount per building is estimated. The second is a cost calculation for selecting lift speeds. We need to calculate the average required number of lifts, construction period and the required material amount per building. With this information, the equipment rental and labor cost can be estimated by lift speeds. The third is to select the adequate lift speed followed by calculating total construction cost in adding equipment rental and labor cost.

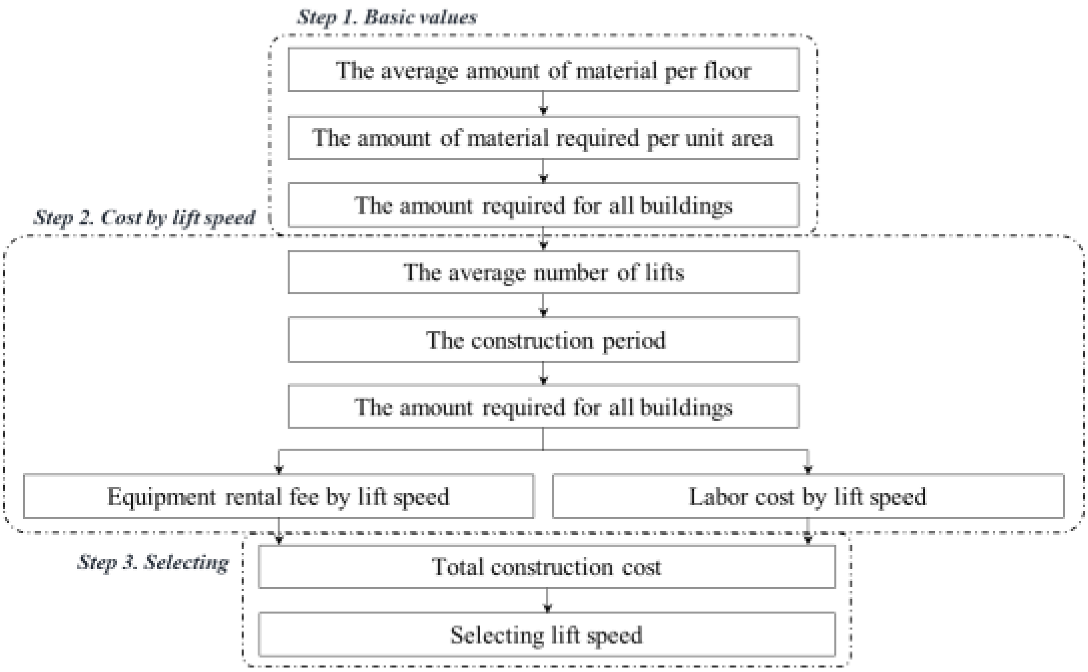

Figure 7. Simulation process for lift selection

4. Conclusion

As increased the number of high-rise buildings, the lifting plan in high-rise constructions directly influences on construction period, construction costs and safety management. Especially, the lift with adequate performance couldn't be selected in every project due to unsystematic lift selections. Current decision making for selecting lifts is dependent on experiences and intuitions of experts so generates many mistakes. Therefore, a systematic system is necessary to choose lifts based on actual field information. This study developed a simulation to select adequate lift speed at each construction. Prior to developing, we collected field information and lift information currently used to progress the simulation. Field information, lift capacity and lift selection way were investigated by choosing apartment houses of Company H located at Sejong, Korea. The basic values were calculated to execute the simulation based on this information. And then we calculated the number of lifts by speeds and the construction period as well as equipment rental and labor costs that could influence total construction costs. Lastly, total construction cost was estimated by lift speeds. So we could confirm that a construction site in this study consumed the lowest construction cost with a speed of 70m/min. This study proposed a simulation summarized in Figure 7. This study suggested a systematic simulation to select a lift so that will be anticipated to use this simulation for more objective and effective applications to construction fields. In addition, it was confirmed that the simulation method through the costing of the lifting speed can increase the efficiency of the project. However, this study could be a just basic research for developing a simulation due to very limited numbers and types of fields applied. This study has limitations in the amount of data collected. In order to make the results of this study more precise, it is necessary to accumulate data over a long period of time. Therefore, it is necessary to verify the efficiency of this simulation with various fields.

5. Acknowledgment

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