An optimized operation algorithm for twin or multi-cage lift systems for high-rise construction sites

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Purpose The objective of this study is to develop an algorithm which can increase productivity of lift operation on temporary twin-cage and multi-cage lifts for construction sites. the algorithm is developed for optimizing operation efficiency at high-rise construction sites. Moreover, it is expected that the algorithm can reduce working hours and traffic queues through operation optimization. **Method** The developed algorithm can optimize lift operation time by using a lifting cycle-estimating method which is generated based on the fundamental concerns when lift scheduling is planned. Lifting cycle-estimation is a vital part for an arithmetic computation based on lift selection algorithm which controls factors such as distance between each lifts, among passengers, and distances among lifts according to moving direction. **Results & Discussion** We carried out surveys and conducted interviews with mechanical and construction professionals to analyse fundamental considerations of material lifting operation planning. We extracted the weight of each of the relevant factors. Based on the weight of factors, we set the lifting cycle-estimate suitable for high-rise buildings. The optimized operating algorithm is extracted through lifting cycle-estimates. Finally, we propose the prototype of an interface that is embedded into the lift with the optimized operating algorithm.

Keywords: *optimization algorithm, operation algorithm, lift car, operating cycle-estimate*

INTRODUCTION

Numerous super high-rise buildings have been built around the world, and many more are planned to be built that are often over 100 stories high[1.] Larger, higher buildings are subject to more restrictions in terms of construction planning and operation.[2] Among them, movement management of materials and labors is closely related to productivity of super-high rise construction, and its importance grows as the buildings become higher.

Currently, at super high-rise construction sites, an experienced site supervisor and operator manage the hoist operation for movement of materials and labors.[3] This lowers efficiency of vertical movement in operating construction hoist. The lift user's queue time increases in higher buildings.

Several construction hoists are planned and built in constructing super high-rise buildings over 100 stories. Unlike elevators installed at the core of the structure, construction hoists are built outside the building, upon the mast, and they are hard to control in an integrated manner. Often construction hoists are operated redundantly, delaying construction schedule in a large project. Given these circumstances, this study conducts a simulation on construction hoist operation, explores how to improve movement of materials and labors in super high-rise construction by developing optimized operation algorithm. The simulation results are assessed based on the cycle time of daily unit work processes according to lifting cycle time calculation (Cho, 2010).

RESEARCH TREND (LITERATURE REVIEWS)

Sacks *et al.* developed an automated lifting equipment monitoring system (Sacks et al, 2005).[4] Cho *et al.* conducted a study on construction hoist operation planning in terms of lifting height and loading (2010, 2011). Further, Shin proposed optimal operation of temporary construction hoists in a super high-rise building based on simulation and genetic algorithm. Before them, most studies focused on the use of tower crane or mobile crane, and other studies on construction hoist tended to emphasize lifting planning rather than lifting operation.

As super high-rise construction becomes more popular in Korea, there is a growing need for a systematic construction planning and site management. The government and private corporations are actively undertaking studies on operation planning of construction hoists and tower crane lifting. Kim *et al.* studied how to calculate a number of necessary construction hoists at super high-rise construction site (2008)[5], and Shin *et al.* proposed a construction hoist movement planning model for super high-rise construction (2010). Cho *et al.* (2011) proposed an algorithm that calculates lifting time in consideration of acceleration and deceleration capability of construction hoists (2011).[6] While there are many studies on construction hoist planning, few have been conducted on the system, management and algorithm of construction hoist operation, with no empirical analysis.

THE CONCEPT OF RESEARCH

Unmanned Smart construction hoist

This study aims to advance construction technology of super high-rise buildings, with a goal to optimize vertical lifting of materials and labors in erecting a super high-rise building. In this study, the control server was connected to construction hoist installed at each mast and to the Zigbee wireless network system. (Fig. 1) Based on the data received from each construction hoist, the study designed a system to give an operating order. Each construction hoist sends real-time data on lifting speed, direction and present load to the control server. The server collects the data, selects the optimum lift and sends an operating order. The focus is on proposing a model that controls many construction hoists at once and operates them, as a preliminary step to develop unmanned smart lift.

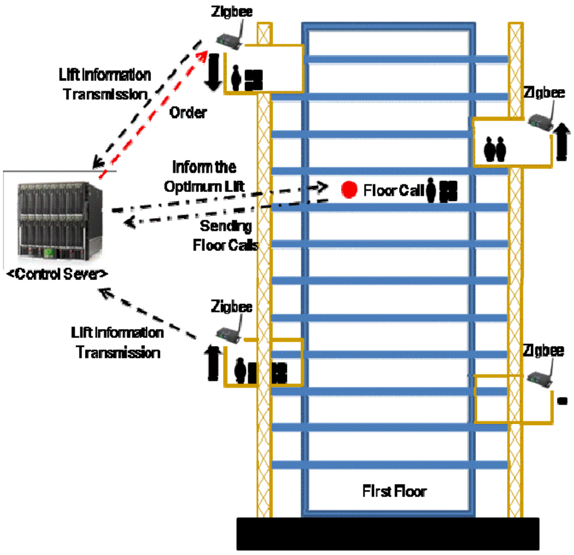

Fig 1. Concept of Unmanned Smart Construction hoist

Twin or Multi-cage hoist operation System

The highest building in the world, Burj Khalifa, used 17 construction hoists during the construction. Each mast is put in different places, depending on the site conditions, and currently, work schedule is made to prioritize the order of materials and labors for integrated management. However, with predetermined schedule, it is hard to flexibly respond to the unexpected situations at the site. Thus, an integrated control system is needed to manage construction hoist operation.

The algorithm flow basically depends on elevator distribution algorithm for labor movement (Fig. 2). The difference is that the control server analyzes condition of the construction hoists by receiving operation data from the Zigbee network.

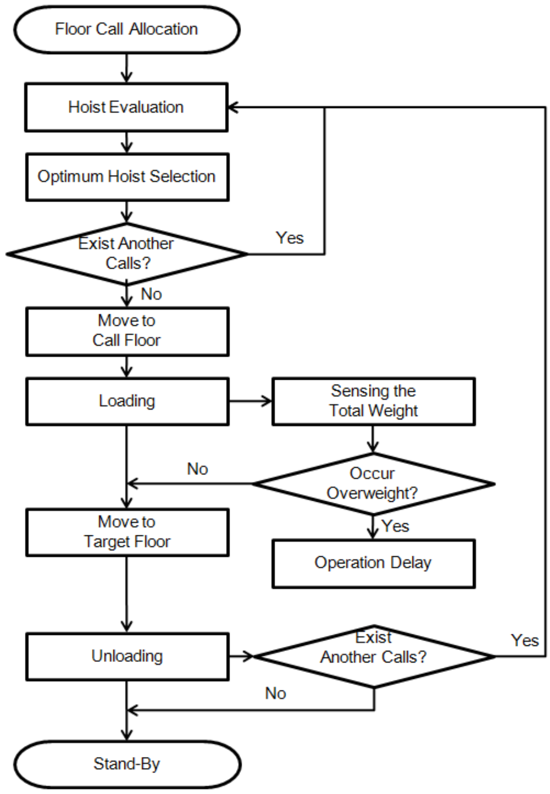

Fig 2. Algorithm Flow of Unmanned Smart Construction hoist

Embedded construction hoist Information

The control server examines algorithm to select the optimum construction hoist, requesting the following data:

1. Velocity of Lift car
2. Position of Lift car
3. Direction of Lift car
4. Real-time available transportation capacity

In this study, a simulation was conducted for the operation information system that manages four construction hoists. Figure 3 illustrates a display device that shows detailed information and operation status of construction hoists on the control server.

Fig 3. Control Box Display showing Hoist info.

Each construction hoist requires information collecting device to send four sets of real-time data to the Zigbee wireless network as shown above. The double sensor type position detector provides information on the direction and position of a construction hoist. In the detector, two proximity sensors read grooves of the internal gear to detect upward or downward movement of a construction hoist, and examines rotation of the rack gear to calculate the velocity.

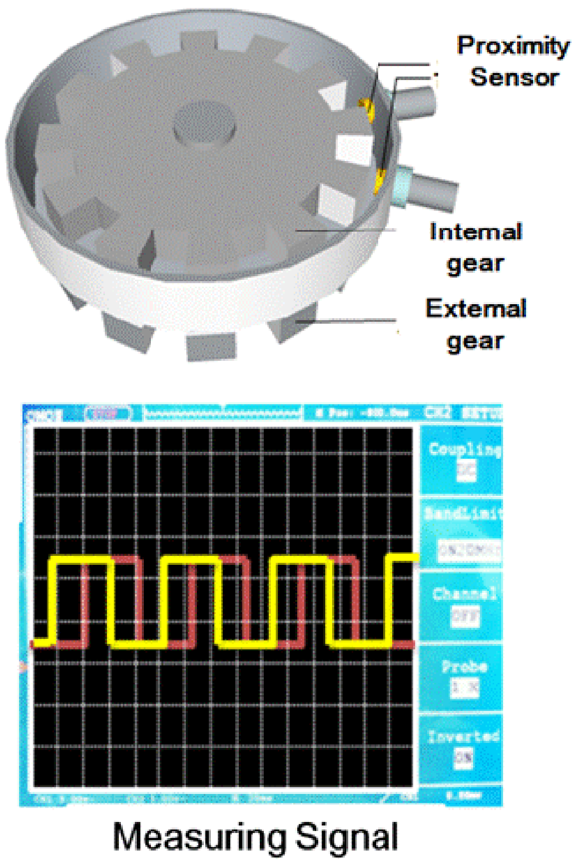

Fig 4. Double Sensor Type Position Detector

OPTIMAL ALGORITHM FOR CONSTRUCTION CONSTRUCTION HOIST OPERATION

Evaluation Method for optimum car selecting

The construction hoist information collected by the sensors is transmitted to the control server through the Zigbee network. The information provides a basis for the algorithm to select optimum construction hoist when the next call comes in. Figure 5 describes the selection flow, how it eliminates unsuitable construction hoists by lift direction, present location and load capacity.

In selecting optimum construction hoist, a primary consideration is the present load capacity; if the capacity is already full, the hoist is instantly excluded. The lift direction and the direction to the call floor are considered in terms of minimizing the movement. Third, travel time is calculated for the remaining hoists to select the optimum construction hoist that minimizes queue time of materials and labors.

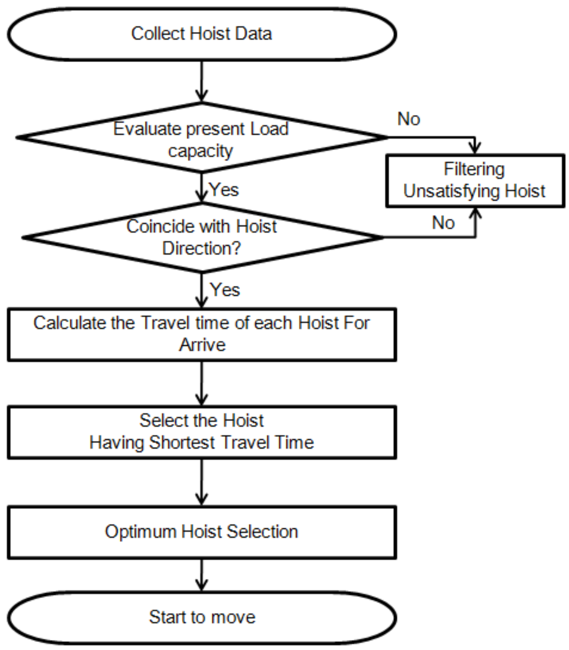

Fig 5. Optimum Hoist Selection Evaluation

Evaluation Method for optimum car selecting

The pseudo code below shows an algorithm system that yields the order of lift car selection based on cycle time calculation. First round of filtering is done between step 1 and 9, considering the present load capacity and accordance of the direction. Second round of filtering is done between step 10 and 17 to select the hoist with minimum travel time.

After the first round of filtering, travel time is calculated for the remaining hoists; the calculation formula are different for hoists that are presently operating and hoists that are idle at the moment. It is because time for power supply, acceleration and reduction should be considered. For example, acceleration time needs not be considered for currently operating hoist; only reduction speed time matters at time of arrival.

Pseudocode for hoist Selection

$i \leftarrow$ ***code number of each construction hoist***
create arrays $Hoist[1 \dots 4]$
$Hoist[i] = -1$
for i $\leftarrow$ 1 to 4
  do if $W_i \leq W_{Mi} \times 0.8$
    if $n - n_i < 0, k_i = 0 \; or \; 2$
    else if $n - n_i > 0, k_i = 0 \; or \; 1$
      then $Hoist[i] = 0$
      return i *that hoist arrays value is* 0
for $i \leftarrow 1 \; to \; 4$
  if $Hoist[i] = 0$
   if $k_i \leftarrow 0$
    do $T_i = \{(n - n_i - h)/V_i\} + S_1 + S_2$
   else $k \leftarrow 1 \; or \; k \leftarrow 2$
    do $T_i = (n - n_i - h)/V_i$
let z *be the smallest value in* T_i
  return i *that is* $T_i = z$

Here,
i : Code number of each construction hoist
W_i : Weight of each construction hoist
W_{Mi} : Maximum capacity of each construction hoist
n : Call floor
n_i : Position of each construction hoist
h : Distance for construction hoist acceleration and reduction
k_i : Direction of previous call of each construction hoist
T_i : Lifting time at operation speed
S_1 : acceleration time
S_2 : reduction time

Travel time for arrival was calculated according to the formula for the simulation method for construction hoist operation plan (Cho *et al*, 2009)

SIMULATION METHOD

Simulation Condition and Model

The following hypotheses were adopted to verify workability of the proposed twin or multi-cage operation algorithm.
First, except for the ground floor, all floors have a same floor height.
Second, the building has two masts and four construction hoists.
Third, when a floor call comes in and a selected construction hoist begins to move, other hoists do not respond.
Fourth, rated velocity, acceleration and reduction time are preset for each type of construction hoist. More specifically, velocity of construction hoist A and D is 100m/min; their acceleration and reduction capacity are 0.60m/sec² and 0.57m/sec² respectively. For construction hoist B and C, the velocity is 70m/min, and their acceleration and reduction capacity are 0.55m/sec² and 0.53m/sec² respectively. In other words, operation speed and acceleration speed are given as constant, not variables, in an algorithm for optimum construction hoist selection.
Fifth, considering that a construction hoist moves materials and labors at the same time, algorithm process identifies construction hoists that are operating over 80% of the load capacity.
Sixth, since this study deals with lifting operation rather than lifting planning, the optimum travel route will be to assign a construction hoist for materials and labors in the shortest time.
An analysis was made on the lifting operating simulation to examine reliability of the optimum construction hoist selection algorithm according to the six aforementioned conditions.

Simulation of Optimum construction hoist Selection Algorithm

The study conducted simulation to measure lifting cycle time of the materials, and the result was compared to the manual construction hoist operation. Currently, an operator judges the floor calls, and sometimes multiple hoists are operated redundantly, lacking information on their status. This happens because an operator merely responds to floor calls without considering the overall management of the lifting operation.

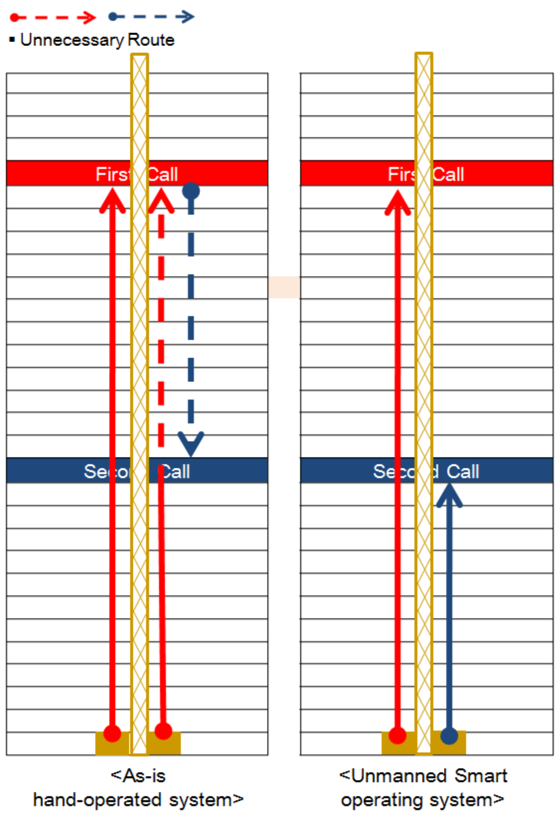

Fig 6. Difference between As-is system and To-be system

The proposed algorithm for selection of optimum unmanned smart hoist uses a formula to decide travel route that reduces total cycle time, and it can solve the problem of redundant operation. The lifting model was based on the lifting cycle time of four construction hoists; assuming that the hoists are in operation, current position, direction, velocity, weight and call order were randomly assigned to each hoist.

Then, floor calls were generated at random floors at a regular interval to calculate lifting cycle time for both the current system and the proposed algorithm for optimum construction hoist selection.

Table 1 Simulation Conditions

Loading/ Unloading Time	0.1 min	Door Open/Close Time	0.05 min
Total floor	30	Number of Hoist	4

	Hoist A	Hoist B	Hoist C	Hoist D
Hoist Model	High Speed	Medium Speed	Medium Speed	High Speed
Maximum Capacity	3000kg	2000kg	2000kg	3000kg
Weight	600kg	1000kg	800kg	0kg
Velocity	100 m/min	70 m/min	70 m/min	0 m/min
Direction	↑	↓	↓	-
Floor	9	27	23	5
Call Floor	15	21	9	-
Target Floor	1	1	25	-

Lifting Priority	Call Floor	Floor call Time	Target Floor
1	13	0:00	1
2	7	0:30	1
3	17	1:00	18
4	29	1:30	13

Cycle time was calculated based on the cycle time calculation formula (Cho *et al*, 2010)[7]

Simulation Result and Analysis

As a result in simulation via simulation model table 1, cycle time data of two masts is table 2 and table 3. When 4 hoists in 2 masts are operated under twin or multi-cage algorithm, in following table2 and 3, every possible duplicated operation can be eliminated. Black marked part means selection of hoist at floor call is occurred.

When 4th floor calls are occurred through simulation condition of table 1. The time spending for total lifting is 154.25sec considering material loading time and door-open time.

Table 2 Operation Cycle Time <Mast 1>

	Hoist A		Hoist B		
Event	Direction (↑/↓)	Position (Floor)	Direction (↑/↓)	Position (Floor)	Time (sec)
Floor call A	↑	9	↓	27	0.00
Arrive floor call A	-	15	-	21	19.62
Floor call B	↓	12	↓	20	30.00
Arrive floor call B	↓	3	↓	14	49.70
Floor call C	-	1	↓	11	60.00
Foor call D	↑	11	↓	2	90.00
Arrive floor call C	-	17	-	1	104.81
Finish Events	-	18	-	1	154.25

Table 3 Operation Cycle Time <Mast 2>

	Hoist C		Hoist D		
Event	Direction (↑/↓)	Position (Floor)	Direction (↑/↓)	Position (Floor)	time (sec)
Floor call A	↓	23	-	5	0.00
Arrive floor call A	↓	16	-	13	19.62
Floor call B	↓	12	↓	12	30.00
Arrive floor call B	-	7	↓	4	49.70
Floor call C	↓	6	-	1	60.00
Foor call D	-	1	-	1	90.00
Arrive floor call C	-	1	↑	7	104.81
Finish Events	-	1	-	25	154.25

Conclusion and further study

In this study, we proposed an unmanned smart lifting system and devised an optimum construction hoist selection algorithm on twin or multi-cage. And estimate the productivity of proposed system through simulation method. Proposed algorithm is considering hoist velocity, direction, position and weight capacity. Using optimum construction hoist selection algorithm process, eliminate all the duplicated call operation and minimize the queue time of materials and labor.

But, the detailed mechanic design of this system should be subjoined. Through searching the limitation factors of wireless network in construction site, we can consider optimization of information transmission between each construction hoist and central control server.

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