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Lifting Load Recording and Management Method of the Lift for Construction Based Sensing Information

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Abstract While buildings in recent days become taller and larger, many problems occur during the management of construction. Particularly, as the vertical movement of manpower and materials during construction has become longer while the lifting frequency and load increase, the need for a good lifting management practice is also increasing. Therefore, this study presents a real-time lifting performance monitoring system that can store and manage lifting records for construction management. Through review of literature and preceding studies related to construction lift, the concept of lift planning and operation management was understood, leading to the development of a system to monitor lifting operation and performance information. This system enabled quick measurement of the lifting performance during construction phase while responding to changes in the project schedule. To verify this system, a case study was conducted in which the current status and characteristics of the sensing-based lifting performance were derived.

Keywords Construction Lift, Lifting Record, Lifting Performance, Object Recognition Technique, Monitoring Of Lifting, Building Automation

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1. Introduction

1.1. Research Background and Purpose

In the past few years in Korea, the number of high-rise buildings constructed in downtown areas, where spatial efficiency is maximized, has increased rapidly due to the advancement of building structures, materials and technologies as well as urban concentration of population and rising land prices. However, as buildings become taller and larger, many problems occur during the management of construction. In particular, as the vertical movement of manpower and materials during construction has become longer while the lifting frequency and weight increase, the need for a good lifting weight management practice is also increasing.

In addition, as the proportion of the vertical lifting of resources increases during the construction process, many restrictions are encountered, hence, raising the significance of a good recordkeeping of vertical lifting for manpower and materials utilized during construction. However, at present, lift management in most construction sites is operated based on the ad hoc lift operation plan and the experiential basis of the site manager. Since the 1990s, efforts to improve lift planning and management of sky-scrapers have been made steadily on both research and operational levels, but research on construction lift was relatively insufficient. In addition, the shift of the construction industry from the existing analog-oriented structure to digital base is raising the expectation of a new unmanned construction era.

Therefore, this study analyzes the operation of construction lift used in the existing construction site and develops a lifting performance monitoring system that proposes a method for storing and managing real-time lifting records for new lifting management, thereby creating a lifting history during the construction period. It is expected that this lifting history can be the basis for patterning future lifting usage while establishing the lifting plan standard as well as forecasting future lifting needs and frequency.

1.2. Research Scope and Method

This study intends to record and manage the lifting history of construction lift based on sensor information. A

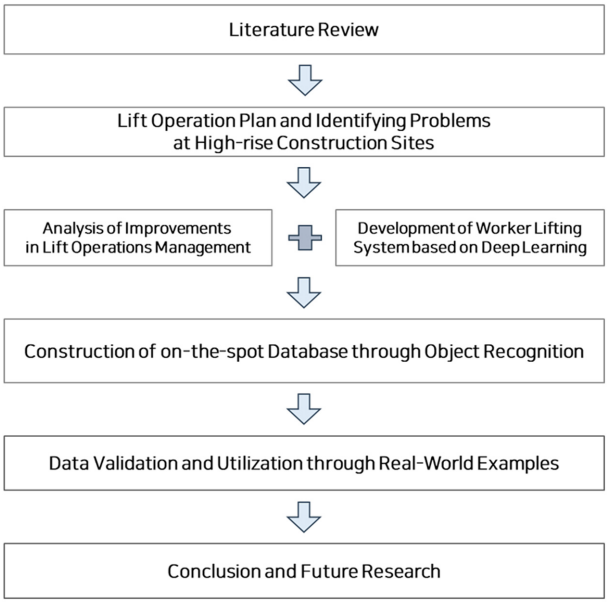


Figure 1. Flow chart for research.

system was developed that can convert lifting performance to data based on accumulating operation data collected from unmanned lifts used at many construction sites and utilizing deep learning-based object recognition techniques. Furthermore, the case study where the system was applied at the test site, confirmed future applicability of the lifting performance monitoring system developed. A 40-plus story building construction project where lift plays significant role in construction was selected as a test site.

The research scope and method for each detailed phase are summarized as follows and Figure 1 below.

1. Literature review of preceding studies - Preceding studies on construction lifts were examined through extensive review of prior literature and studies. Through this, the concept of lifting plan and operation management of construction lift was understood.
2. Designing lift monitoring system – The structure of lifting performance monitoring system developed in this study and the method of specifying and recording all component elements are presented. Through this method, it is possible to quickly measure the lifting weight during the construction phase while obtaining lifting information that alters flexibly in response to changes in the construction operation plan.
3. Case study on field application – The monitoring system proposed in this study was applied to the case site, and the status and characteristics of sensor-based lifting performance records were derived.
4. Conclusion and future research – The conclusion of the study was presented, and future research was discussed.

2. Literature review of preceding studies

Research on the lifting of construction lift has been actively conducted as the number of skyscrapers increased. In addition, as the height of buildings increased, the lifting time of resources became an important factor taking up a large proportion of work efficiency at the construction site. Accordingly, the research on lifting was classified into lifting plan and lifting management, and significant studies are summarized as below.

Ahn (2004) suggested the vertical movement planning process of workers through ideal simulation, and Kim et al. (2008) presented an objective and systematic method of calculating the number of heavy lifting loads. Kim (2008) suggested a lifting information management method through a survey on the actual condition of the lifting plan of a skyscraper, and Lee et al. (2008) presented the optimal method of selecting lift for efficient site-specific lifting plan. Shin (2011) and Won (2011) each presented a realistic process establishment using a genetic algorithm for the building construction lift planning system and a process linked to the calculation of construction task-specific lifting load and schedule.

Lee et al. (2008) presented a lifting management system by proposing a waiting time simulation model for materials and manpower based on the queuing theory. Cho (2011) developed a lifting time algorithm for construction lift while Won (2013) and Lee (2014) proposed a lifting operation support process through a material lifting plan and management model relevant to finishing tasks. Moon et al. (2014) suggested a lift management method through an optimal transfer floor search method that minimizes the travel time of workers.

Literature review of prior studies on lifting revealed that prior studies focused more on lift planning and equipment selection rather than on practical lift operation management during construction. Even in the current construction projects, lifting is still in the planning stage and it is difficult to revise the lifting plan that follows the rapidly changing operational plan, thereby diminishing the reliability. Accordingly, it is imperative to build a systematic lifting management system and the system for performance and management of construction lifting will be proposed in following section.

3. Lifting Performance Monitoring System for Construction Lift

3.1. Lift Operation and Lifting Information System

The lifting performance monitoring system proposed in this study utilizes real-time lift operation based on sensor information and object recognition technique of deep learning technology. The lifting manpower digitization process was designed by combining sensor information and deep learning technology, and each phase was systematized so as to build a monitoring model for manpower lifting. To accomplish this, it was necessary to install equipment that can collect construction lift information at the actual construction project site.

3.1.1. Lifting Operation Performance

In order to understand the real-time operation status of construction lift, various sensors were installed on the lift and each collected data was stored in the data storage which was then used for analyzing lifting performance. Preceding studies have already used various sensors to acquire lifting performance information and this study particularly installed a camera for image collection that can be used to accurately determine the lifting performance. Table 1 shows the equipment used in this study.

3.1.2. Deep Learning-based Object Recognition Technique

Deep learning technology was applied to understand the real-time lifting status per each floor where workers are using the construction lift. The deep learning-based object recognition technique can identify and count the number of workers inside the lift by recognizing the hard hats worn by the workers. This was feasible since workers are always wearing hard hats inside the lift where similar condition is maintained on a repeated basis. The computer vision of deep learning is a key technology that can detect and record changes in personnel inside the lift. In order to find the most suitable object recognition technique, various methods were investigated and cross-checked for their performance and purpose. Table 2. shows the comparison of different object recognition techniques.

As shown in Table 2, different object recognition methods present different characteristics. Among them, You Only Look Once (YOLO) presents new approach for object recognition using a simple convolutional neural network (CNN), which can process images in real time at 45 frames per second. As such, YOLO was selected as the image object recognition technique considering the characteristics of lift that frequently changes internally and the accuracy as well as the speed of processing results.

The image object recognition procedure using YOLO is as follows.

1. Creating image frame group sampling for object recognition
2. Running a single CNN on an image
3. Detecting result based on the reliability of the Neural Network model generated
4. Repeating movement of frame groups and process analysis

As shown in Figure 2, the bounding boxes of each convolutional network step calculate the reliability of the image. In the initial stage, the image reliability may be low, however, the recognition accuracy can be improved over repeated frame analysis through adjusting the position of bounding box.

3.2. Measurement of Lifting Users

3.2.1. Training of Hard Hat Detection as an Object Recognition

As a method for counting the number of workers

Table 1. Lifting operation performance storage device

Case	Equipment	Output data
	Data Processing board	- Lift position - Date and time - Data storage
	Encoder Sensor	- Travel distance - Speed - Stop floor
	Calling Device	Number of call floors and direction
	Unmanned lift board Destination floor	Destination floor
	IP Camera	- Picture - Video

Table 2. Examples of deep learning-based object recognition

Examples	Characteristics
R-CNN	- Testing time per image 50 seconds - The mean average precision (mAP) for each query is of 66% on VOC 2007 test-dev.
Fast R-CNN	- It builds on previous work to efficiently classify object proposals using deep convolutional networks. - Achieves near real-time rates using very deep networks, at 2s per image. Multi-scale design based on anchors, computed on a single-scale image.
Faster R-CNN	- It is a single, unified network for object detection. - It does not need external region proposal. - The test-time speed of obtaining results is of 200ms per image.
You Only Look Once(YOLO)	- It processes images in real-time at 45 frames per second. On a Pascal Titan X it processes images at 40-90 FPS. - YOLOv3 is extremely fast and accurate. And you can use image, video, Real-time detection on a Webcam.
Single Shot Detectors(SSDs)	- The SSD approach is based on a feed-forward convolutional network that produces a fixed-size collection of bounding boxes and scores for the presence of object class instances in those boxes, followed by a non-maximum suppression step to produce the final detections.

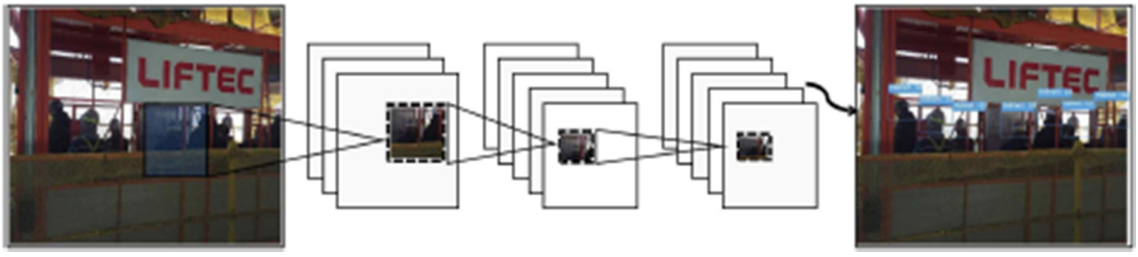


Figure 2. Hard hat recognition using object recognition technique.

engaging the lift, an approach of recognizing and counting hard hats worn by workers was adopted. As a first step, a hard hat recognition system using an object recognition technique was constructed. The first task in hard hat recognition requires constructing CNN and selecting and sorting images to be trained. Since all workers at the construction site are required to wear safety hard hats, hard hat was selected as the object recognition target which was used for deep learning training. The conditions for training the hard hat recognition, thereby improving the recognition rate are as follows. Figure 3 shows sample data and coordinate values for deep learning training.

1. Training on various types of hard hat images
2. Extracting appropriate coordinates for each image
3. Considering images with various brightness and colorations so as to reflect natural environmental condition that frequently changes

Preparation for the training was completed by matching each picture containing image of hart hat worn with RGB coordinates. To enhance the recognition rate, various types of hard hats and images of hard hats taken from various angles were considered.

3.2.2. Detecting Changes in the Number of Workers within the Lift

As shown in Figure 4, the number of workers who got off from the lift on certain floor can be determined by comparing the number of workers taking the lift when it started to move and the inner condition of the lift after making a stop at the destination floor. By comparing the difference in the number of lift users detected through object recognition, data on the number of workers per hour on each floor can be collected and corresponding lifting performance record can be created. Figure 4 shows the operational flow for recording lifting within the current process.

3.3. Patterning of Lifting through Data Matching

In construction industry, iterative processes are performed vertically to ensure that the work is continuous and consistent. The lifting history data module can be utilized as an efficient tool to check the current progress of construction compared to the project schedule. In addition, it is possible for construction managers to obtain objective data-based construction trend information for monitoring construction projects.

3.3.1. Process and Lifting Data Usage

In order to utilize the lifting history during construction project, it is necessary to link the lifting data and the characteristics of the construction work schedule. Therefore, the concept of TACT technique used for data classification

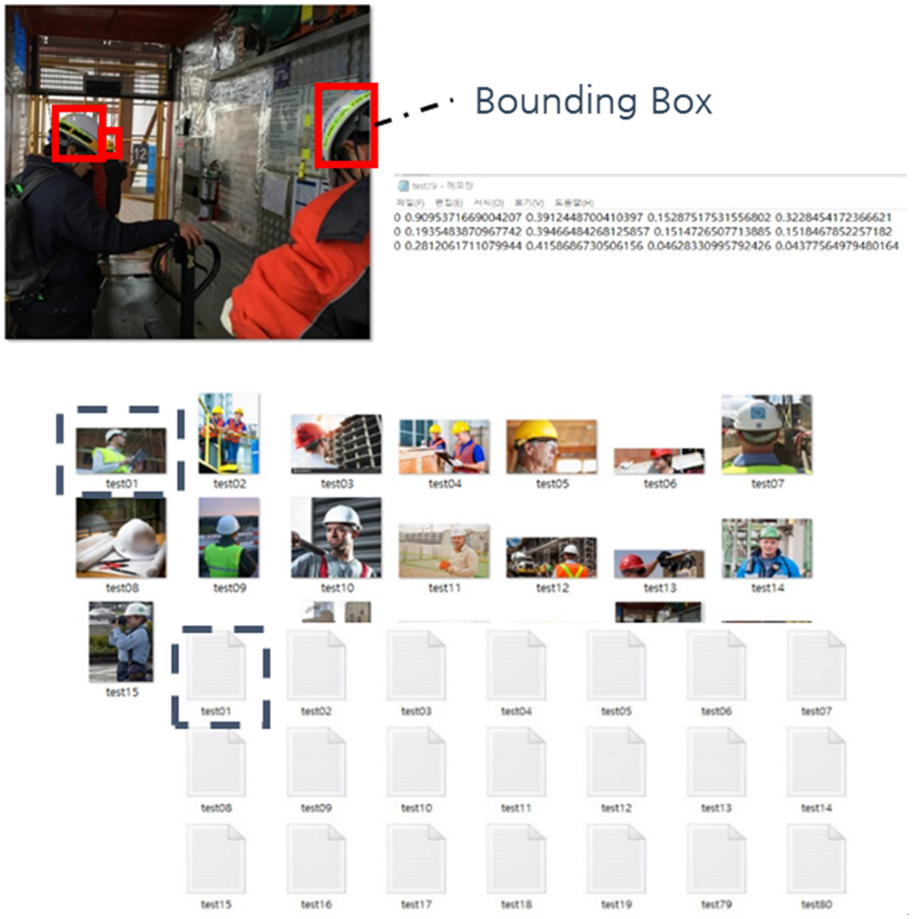


Figure 3. Coordinate extraction for training.

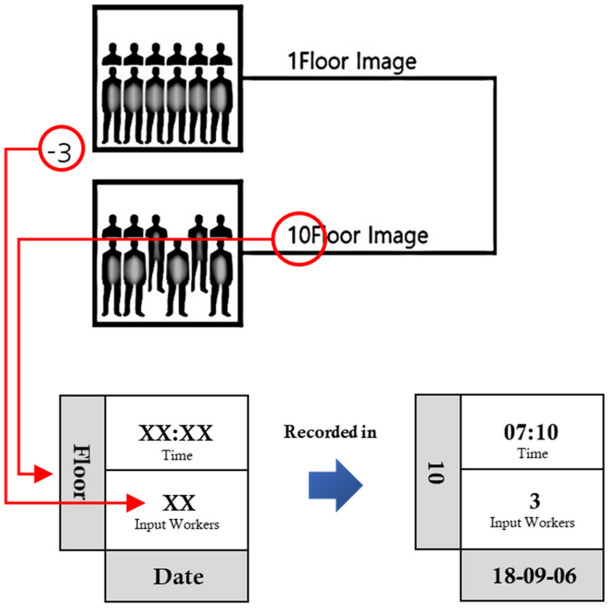


Figure 4. Detecting and recording changes in the number of lift users.

was applied in this study. The TACT technique is a finishing construction management method that subdivides work into each floor and process, distributes manpower and materials equally, and performs construction by adjusting the relationship between the preceding and following tasks of the same floor. When project work scheduling based on TACT is used on construction sites, patterns in data can be identified because work is performed the same way within a consistent cycle. With this arrangement of data, it is possible to analyze the work progress so as to find the causes of delays and to make modifications to the work schedule. Figure 5 illustrates the process of analyzing the project schedule and patterning the lifting data.

3.3.2. Work Schedule Analysis and Patterning of Lifting

Patterning the project schedule that reflects the process plan and site information requires subdividing major projects being undertaken and labeling each task as shown in Figure 6.

The construction manager can conveniently grasp the status of work progress based on the tasks recorded in TACT format which can also be used as an indicator for future work schedule adjustment. As shown in Figure 7, by linking the lifting data to the work schedule listed in chronological order, the lifting trend and expected lifting frequency can be managed.

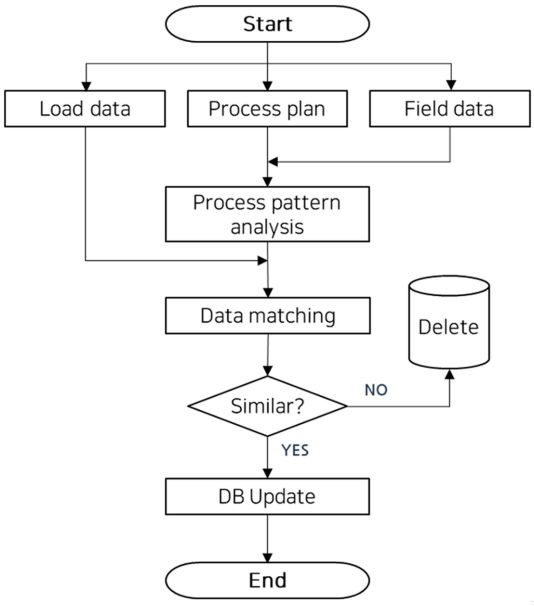


Figure 5. Process and load data matching flowchart.

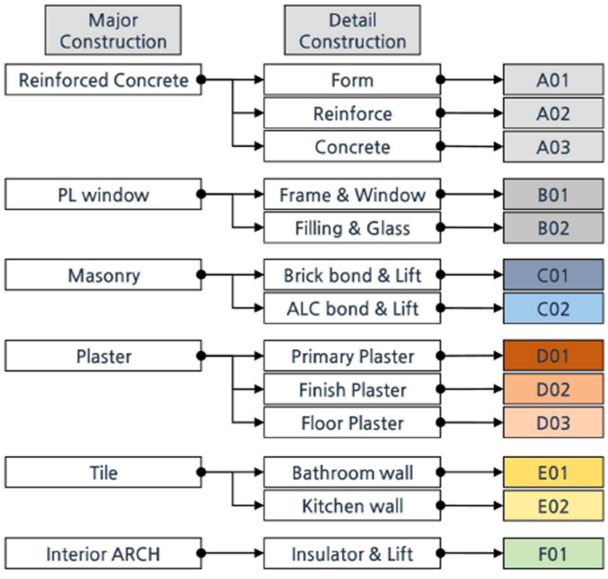


Figure 6. Main construction subdivision and labeling.

The work force assigned to the construction project is calculated according to the project estimation. Although construction management based on TACT technique is effective in the operation process of each work task, the actual input of manpower and the frequency of lifting required are not taken into account. Therefore, this study collected and analyzed the operation of construction work and monitored the lifting pattern so as to supplement the lifting operation plan at the site and present objective data of the lifting manpower per each work task.

4. Application of System Through Case Study

In order to verify the efficiency of lifting performance monitoring model developed, construction operation was monitored, and data were collected from a 49-story building project currently under construction. The case study project site is located at Ilsan, Goyang-si, Gyeonggi-do, and the project involved building a studio apartment. The site information is summarized in Table 3 below.

4.1. Acquiring Operational Performance Information of Unmanned Construction Lifts

A fully automated, unmanned construction lift system was being used at the case study construction site. Unlike a manual lifting system operated by a temporarily employed

Table 3. Case study construction site overview

	Features
Project type	Office Project
Construction Duration	2016. 01. 04 ~ 2019. 05. 31 (41month)
Site area(m^2)	16,631.10
Gross floor area(m^2)	171,140.93
Usage	Office, Apartment
Scale	B3F ~ 49F
Maximum Lifting Height(m)	165.5
Measurement target	Worker
Monitoring duration	2018. 08. 21 ~ 2018. 09. 20(31 day)

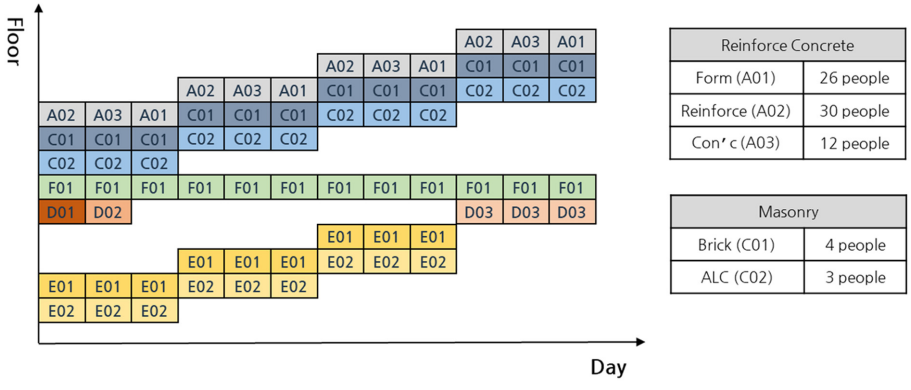


Figure 7. Lifting process pattern and lifting data.

Table 4. On-site lift use

	Twin Type		Single Type
	Lift A	Lift B	Lift C
Capacity	2 ton, 22people	2ton, 22people	1.5ton, 16people
Usage	People/Freight	People/Freight	People/Freight
Lifting Range	1F ~ 49F	1F ~ 49F	1F ~ 49F
Speed	100 m/min	100 m/min	100 m/min
Distance for acc.	2.8 m	2.8 m	2.8 m
Time for acc.(sec)	2.33	2.33	2.33

lift operator, the unmanned lifting system can identify its position, speed, and direction of movement through various sensors installed on the lift and transfer this information to the central control system. Specifically, sensors installed on the lift can collect and record operational information, detect the time and the floor level where the lift makes the stop and also identify changes in the number of lift users. Table 4 summarizes the lifting use and operation recorded from the case study project site.

By installing a camera and encoder sensor on each unmanned construction lift operated through sensors, operation information and lifting records can be collected. The collected information is a factor that can increase the efficiency of lifting operation and can be used for flexible lifting management that can cope with process changes, such as express lifts and vertical zoning.

4.2. Measurement of Lifting Users

Real-time monitoring of the number of lift users was performed by linking information, such as the lift location, time, and direction of movement collected through each sensor installed on the on-site unmanned lift with the information regarding the number of workers inside the lift which was acquired by the camera installed. The number of lifting users measured through comparison of the hard hat recognition and each data were rendered as a 10-minute unit data. Finally, the daily time-series lifting users was obtained for the total measurement period.

4.3. Recording and Management of Lifting Data

4.3.1. Linkage of Lifting Performance and Project Schedule

The process of linking the lifting performance and operation data collected from the lift with the data for each detailed work type is shown in Figure 9. In the case of studio apartment project used for the case study, each work type has the characteristic that the succeeding activity is carried out after the preceding activity is completed. In addition, it was observed that the floor level of work

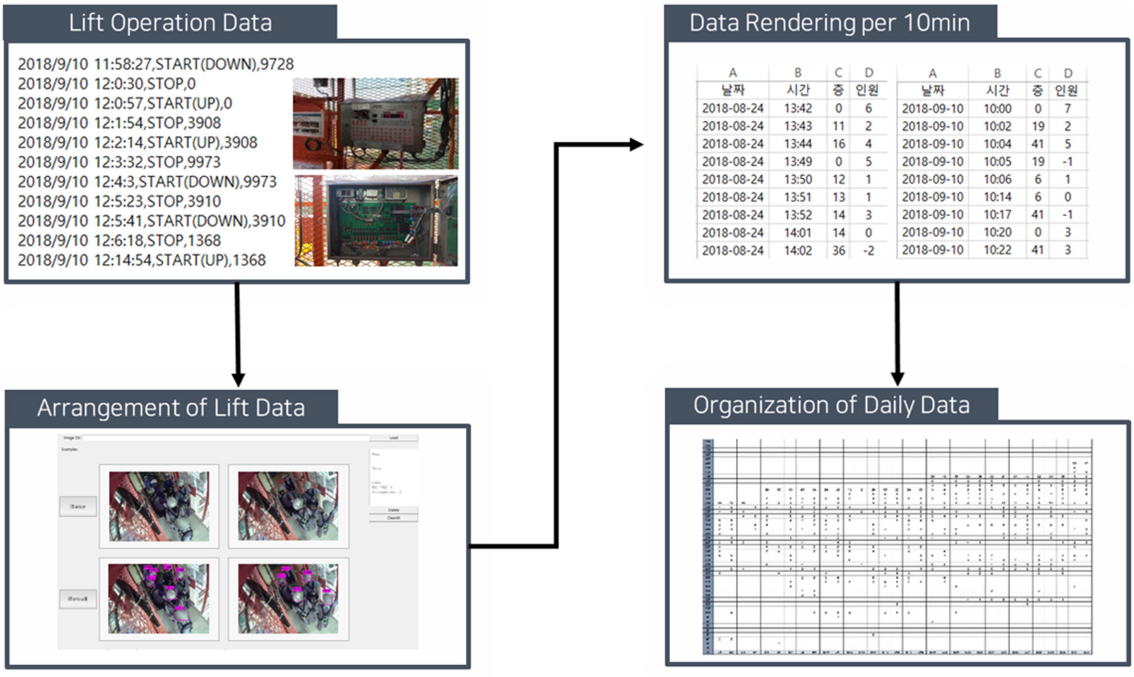


Figure 8. Quantitative manpower analysis.

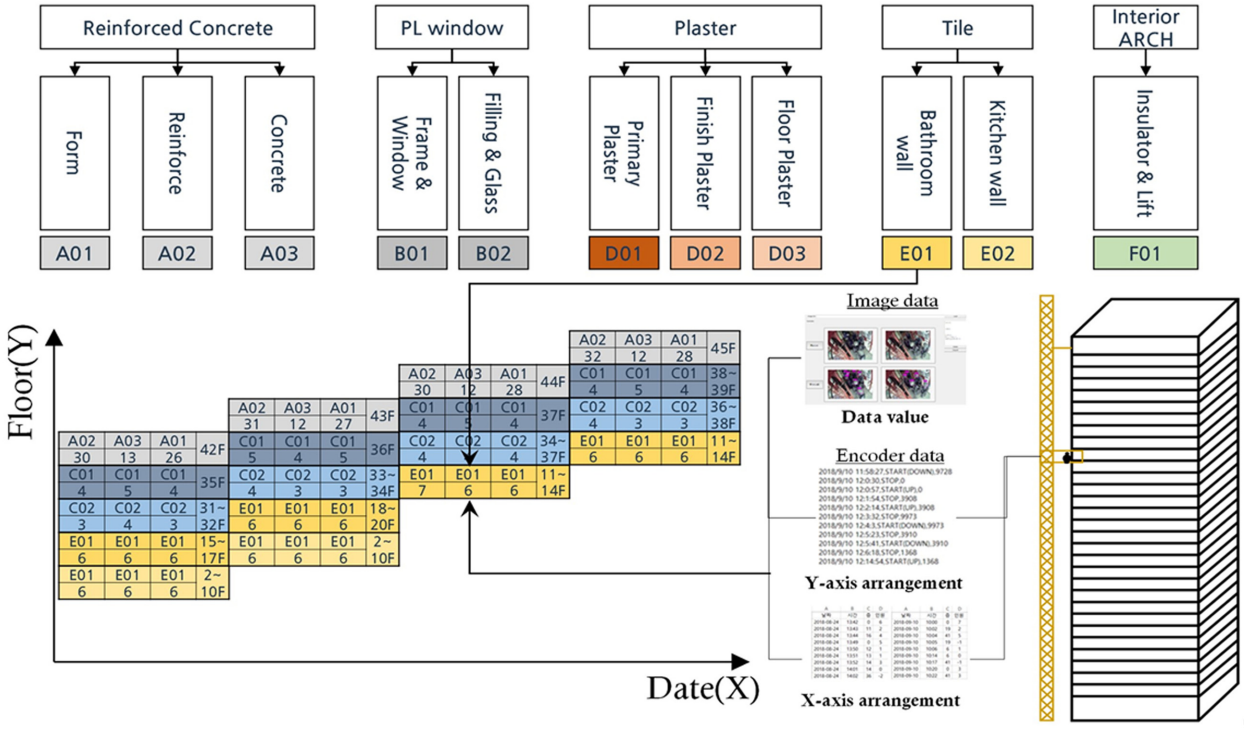


Figure 9. Linking lifting performance and project schedule.

Table 5. Workforce comparison by activity

Main Event		Code	Input Workers (A)	Measurement Workers (B)	*Deviation (A-B)*
Reinforced Concrete	RCS, Form	A01	26	28	2
	Reinforce	A02	30	32	2
	Concrete	A03	12	13	1
PL Window	PL Frame & Window	B01	5	5	-
	Filling & Glass	B02	6	5	-1
Masonry	Brick bond & Lift	C01	4	5	1
	ALC bond & Lift	C02	3	4	1
Tile	Bathroom wall tile	E01	3	3	-
	Kitchen wall tile	E02	3	3	-

in progress was raised in the order of time. Moreover, the average number of required workers was maintained by continuously saving the workers required to perform an activity that was repeated over a period of time, which can be utilized as the company's own standard cost estimation.

4.3.2. Lifting Load Prediction Process

In general, it is very difficult to perform construction work according to the work schedule due to external conditions and yet, the construction schedule normally is not revied and updated in a timely manner. However, through the method of recording and managing lifting operation presented in this study, it is possible to accumulate the lifting performance information and to predict the lifting frequency on any specific day by linking the work schedule. Moreover, it is possible to revise the schedule versus actual performance of each work through the linkage between data while modifying the project schedule ahead of time. Figure 10 shows the process of modifying the activity schedule and estimating the frequency of lifting needed on any specific day by linking the lifting record and the work schedule.

Comparison of the Number of Workers per Activities

Table 5 summarizes the estimated number of workers required for each activity and the actual number of workers utilized to perform the activity in comparison. Comparing the difference between the total number of workers estimated during the planning phase and the actual number of workers used, it was found that the

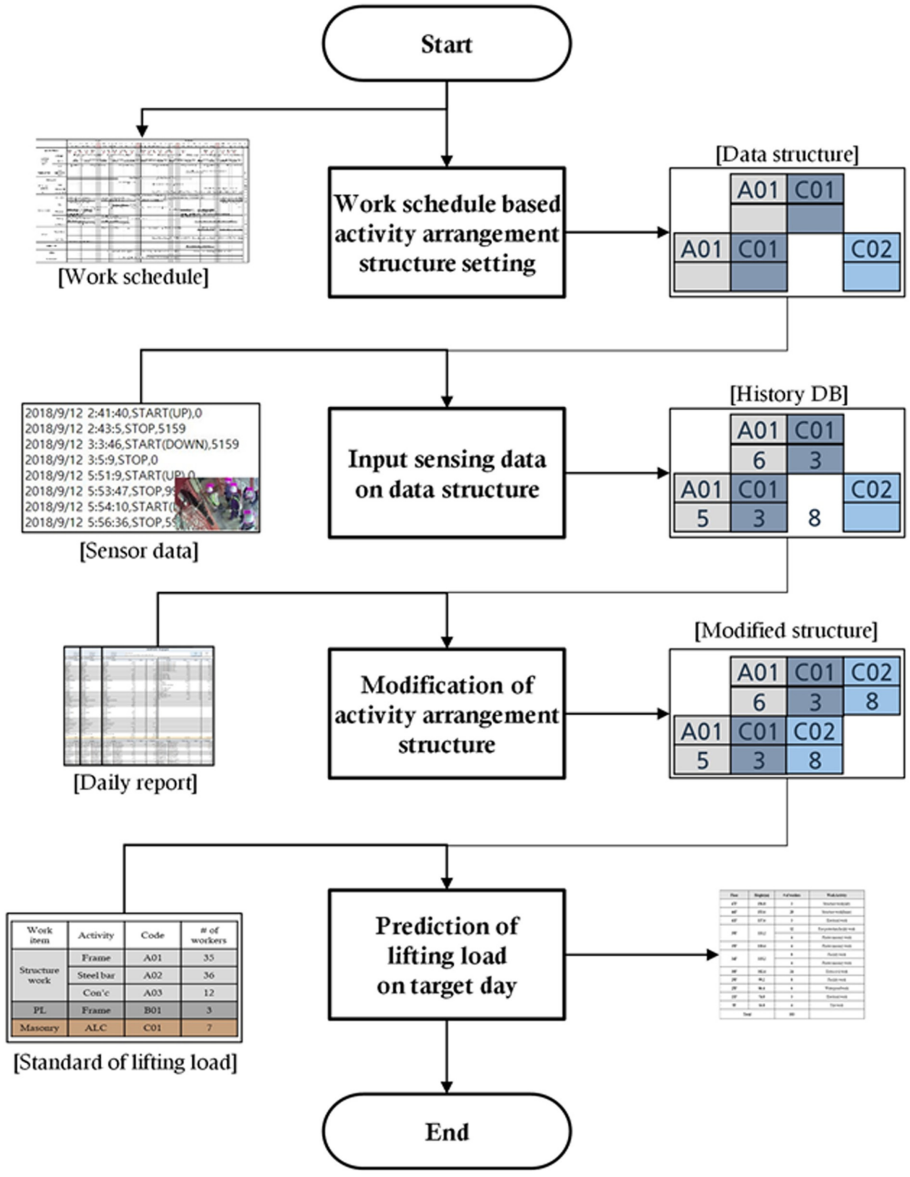


Figure 10. Lifting load prediction process.

difference was marginal proving the viability of measuring the workforce required through lifting operation analysis. In addition, the lifting load performance data can be used as an objective data for future lifting operation and management that coincides with the work schedule. Furthermore, the company can establish its own estimation standard for each work package through continuous data accumulation.

5. CONCLUSIONS

As buildings become taller, domestically and internationally, the vertical movement of materials and manpower has increased. Subsequently, studies on the lifting plan during planning phase have been actively conducted. However, the lifting plan established during planning phase was not accurate enough to respond and address the variations of lifting requirement during the construction stage and not enough studies focused on this issue.

As such, considering the active construction of high-rise building projects at present, this study attempts to improve the lifting operation by proposing the method of recording and managing lifting operation based on actual data so that planning of lifting and operation at the project site does not solely rely on the judgement and experience of site manage nor remains only as a plan. The study results are as follows.

First, this study endeavored to collect operation performance data of a construction lift using sensor modules. As a result, a sensor module was developed to record and collect operation information and lifting performance of an unmanned lift used in high-rise construction projects. The encoder-based sensor device records the moving

direction, stoppage, travel time, and location of the lift while the camera-based sensor module detects and records the number of workers getting on or off the lift at each floor. The object recognition technology targeting worker's hard hat was used as a means to automate and increase the level of accuracy of monitoring the lift operation.

Second, the lifting frequency prediction model based on lifting record and project schedule was presented. By linking the project schedule with the lifting operation performance data collected through sensors, the prediction of expected lifting frequency on a specific work schedule was inferred. This system allows monitoring of the number of workers on each floor, allowing adjustment of the number of workers for the daily work activities assigned to each floor.

Third, the use of lifting performance data based on objective evidence was proposed. Due to the nature of construction work susceptible to external conditions, it is difficult to follow the project schedule verbatim and perform accordingly. In particular, in the case of high-rise construction, it is very important to manage conflicts between activities where conflicts occurred due to delays since the vertical movement of materials and manpower greatly affects the progress of construction. Through the lifting performance data obtained in the study, it is possible to objectively identify and prepare for the expected date of conflict between activities. In addition, by analyzing the deviation between the number of workers estimated for each activity and the measured, actual number of workers engaged on activities, the company can establish company specific estimation standard.

This study contributes to the body of knowledge by proposing a system for acquiring and managing lifting data that can be used in actual operation stage overcoming the limitations of existing construction lift-related research that mostly focused lift planning. The data-based construction lift operation method proposed in this study can be effectively applied to various equipment used in construction sites. Since the operation of all equipment used in the construction site closely follows the work schedule, more research should be conducted on data generated during the construction process. In addition, this study demonstrated how real-time update is possible by reflecting the data of the construction site that varies according to the work sequence. This demonstration can be useful in decision-making for construction equipment operation. Through this, the construction site can expect improved productivity and smooth operation.

In future research, continuous cooperation with field managers should be used to match the monitoring of workers' lifting need with more detailed work units so that workers deviating from a specific floor are identified, thereby increasing the accuracy of estimating the number of workers using the lift. Moreover, the application of object recognition technology should be extended to lifting of material which requires further testing. Through integrating the lifting flow of material and manpower, it is possible to establish an optimal strategy in determining the period of use of the entire project equipment.

6. Acknowledgments

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