Data-Processing Model for Vertical Zoning based on Construction Lift Operation Records for High-rise Building

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Abstract

As recent buildings have been getting higher and larger, vertical construction lift planning and operation are key factor for successful project. Although many studies have been trying to set up a construction lift planning system at early stage before lift installation. But there are not regarding real-time control system for lift during construction stage. In this study, we use sensor module and real-time data storage device named ELIS(Embedded Lift Information System) to collect the lift operation data for improvement of vertical zoning efficiency. Lift operation data linked with finishing work activities is utilized to predict to-be lifting events by data processing. This procedure analyzes the pattern of lift moving. Finally, we propose optimum vertical zoning performance simulation method based on post processed lift operation data from ELIS. This system aims to update and to provide daily optimum vertical zoning. We expect that operation data based decision making for vertical zoning can contribute to finishing work planning in complex and tall building construction over 400m.

Keywords –

Construction lift, Vertical zoning, ELIS(Embedded Lift Information System)

1 Introduction

For the recent past few years, buildings in the world became high-risen. Hereupon, there were various restrictions about the plan and operation of construction. Among them, lift management of the workers and materials for finishing work of skyscrapers have been an important issue as the most important element required when managers considerate productivity and cycle of construction.

The vertical movement of materials in the field has been to be very complicated because the buildings have become high-risen. Especially, as the vertical distance for moving became longer than before, it was very difficult to rationally manage it. It is difficult for individuals who made a decision on the lift management on skyscraper by just using their long accumulated experience and intuition. It causes increase of labor's queue time to use lift in high-rise building.

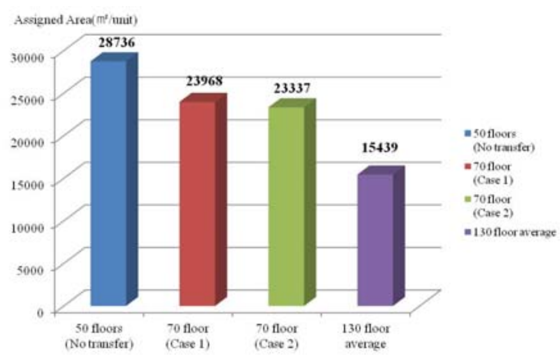

Figure 1. Assigned area per unit cage according to building's number of floor

When establishing the lift management in the stage of construction plan, there are various practical and influential factors that should to be dealt with in the mathematical model consisting of simplified formula or exploratory technique. Especially, number of lift, selection of lift and location are reflected to the period of lift installation, quantity of material and packing method in the early stage. Many kinds of technique have been used to estimate plan of lift equipment. However, currently vertical zoning only has been decided based on labor's commuting time or restrictions during peak-time.

Shin(2011) classified vertical lifting management into two elements; moving plan and movement operation. And he indicated the importance of monitoring or operation management during construction period as important as lift plan. Compare to low-rise building, high-rise building needs additional ration on cost including equipment planning. If different project sites use same lift system, in other word, according to number of floors assigned area per each cage is decreased shown as Fig 1.

2 Research Trend

Sacks et al. developed an automated lifting equipment monitoring system (Sacks et al, 2005). Cho et al. conducted a study on construction lift operation planning in terms of lifting height and loading (Cho, 2011). Further, Shin proposed optimal operation of temporary construction lifts 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 lift 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 lifts and tower crane lifting. Kim et al. studied how to calculate a number of necessary construction lifts at super high-rise construction site (2008), and Shin et al. (2010) proposed a construction lift movement planning model for super high-rise construction. Cho et al. (2011) proposed an algorithm that calculates lifting time in consideration of acceleration and deceleration capability of construction lifts (2011). While there are many studies on construction lift planning, few have been conducted on the system, management and algorithm of construction lift operation, with no data based access.

3 Construction Lift Operation Model

3.1 Daily Lifting Pattern on Site

There is a necessity of distinguishing the operation types and patterns to analyze operation states in the field of project. Ahn(2001) and Cho(2011) have divided the daily lifting time into material lifting time, moving time of operators, combined lifting time for employees/materials, lunch time, and peak-time.

Previous studies dealing with characteristics of daily lifting time have distributed the lifting time of materials before and after lifting time of employees. However, according to the result of examining characteristics of actual operation, lifting time of materials was turned out to frequently occur early in the morning or late night due to the expansion of a concept of JIT (Just in Time). Therefore, this study has defined the lifting time of materials into a case other lifting time as shown in the Fig 2.

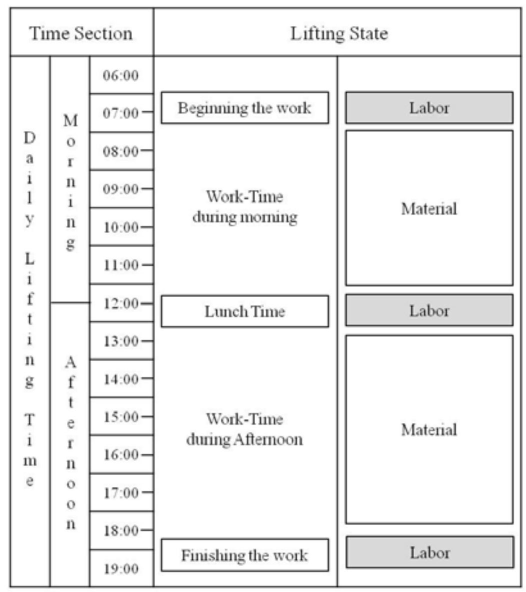

Figure 2. Daily lifting time pattern

3.2 Transfer & Vertical Zoning

A lift applied up to 400m of operation zone has been used for the construction of the highest-risen building in the world at Burj Khalifa. However, a significant construction delay has been caused due to an issue of frequent breakdown of power cable.

Fig. 3 explains the difference between the space zoning type and transfer operation method. Park has suggested optimal space zoning model in reducing the lifting time by setting up the operation zones. Park(2013) has suggested an optimal method based on transfer method.

In addition, as the buildings became high-risen, the daily amount of transported materials has been increased as well. In addition, most of the skyscrapers were built in the form of set-back type due to an issue of slenderness ratio. Therefore, division and setup of lift operation zones have become an inevitable factor.

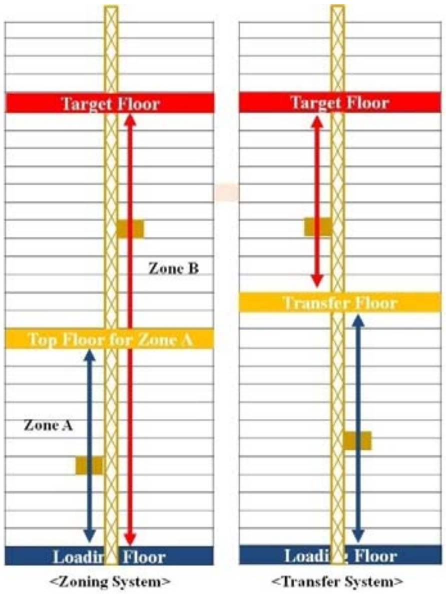

Figure 3. Types of vertical zoning

These studies have setup the commute time of employees as a peak time controlling the lift circulation only during the morning time, increasing available work hours, and preventing the confusion of lift usage. They have utilized result value in the optimized simulation instead of the operation data in the field.

This study is intended to suggest a decision-making process as an alternative of both space zoning method and transfer method depending on the shape of buildings and situations in the field. In addition, this study represents a difference from others aiming to adjust zones based on the database during the operation after installing the lift different from plans for lift operation zones in the milestone for each process, representative finalizing materials, calculation of outcomes per area, and setup for operating group.

3.3 Variables for Operation Management

In order to verify the vertical operation zoning simulation based on the lift operation records suggested in this study, the lift cycle time variables and formulas are used for be reflected on decision-making model by simulation.

Calculation of expected distribution time and entire lift completion for the lift call is performed according to formula (1) to (4). Variables of lift operation are comprised of door-opening time (D_1), door-closing time (D_2), entire moving time (T_{os}), and loading/unloading time (T), and the cycle time consumed for lifting the materials and human resources from the original place to destination is as follows in (1).

$$Cycle = (D_1 + D_2) \times 2 + T_{os} + L \quad (1)$$

$$T_{os} = t_1 + T + t_2 \quad (2)$$

$$T = (H - h_1 - h_2)/V \quad (3)$$

$$t_1 = \sqrt{h_1/a_2} \quad t_2 = \sqrt{h_2/a_2} \quad (4)$$

The entire moving time (T_{os}) is comprised of the total of accelerating time (t_1), moving in a regular speed (T), and decelerating time (t_2). Each of the time factors is stated by standards such as regular speed of distributed lift (V), accelerating/decelerating speed (a_1/a_2), accelerated/decelerated distance (h_1/h_2) and moving distance (H). However, formula (1) indicates 1Cyde comprised of loading or unloading that a total cycle formula for distributing the lift car on the floor given an order is required.

3.4 Embedded Lift Information System

In the current field of construction project, lift management has been taken by field manager preparing for lift plans on a daily basis. However, there is no way to confirm the breakdown of each of the lifts and efficiency of the usage. For this, an effort has actively been exerted to secure a system for collecting information of lift equipment status and operation on a real time basis. Internally installed lift information collecting device in the use of sensor module suggested by Kwon has been proposed for embedded lift information system based on the data on a real time basis. Fig. 4 represents a developed data-box and display to collect operation history data in the ELIS system.

Figure 4. ELIS data-box in construction lift

ELIS system receives location, speed, load, and moving direction on a real time basis from six-tier sensors (encoder, load cell, partitioning converter, current sensor, limit switch, and proximity sensor) installed on each of the lift cars. It saves them on the database for analysis of operation record of each lift during the entire period of project and compares or analyzes data between lifts to establish the operation plans in a near future when reflecting the lift call information received in current time period. Fig. 5 represents data for collecting information of lift on a real time basis.

	Date	Dep. Time	Arr. Time	Ope. Time	Total Time	Call Floor	Target Floor	Distance	Max Speed	Ave. Speed	Power	Load
2	2013-09-06	0:54:11	0:54:30	0:00:19	2:01:52	-3	1	20.23	93	67.3	0.99	0.5
3	2013-09-06	0:54:34	0:54:47	0:00:13	2:02:05	1	-3	5.65	35	30.4	0.02	0.44
4	2013-09-06	2:02:39	2:03:59	0:01:20	3:24:21	-2	23	113.69	93	86.2	3.3	0
5	2013-09-06	2:04:25	2:05:45	0:01:20	3:25:41	23	-3	116.86	93	87.5	0.17	0
6	2013-09-06	2:10:16	2:11:48	0:01:32	3:27:13	-3	26	129.8	93	85.5	3.74	0.25
7	2013-09-06	2:12:06	2:13:34	0:01:28	3:28:41	26	-2	125.98	93	87	0.22	0
8	2013-09-06	2:13:59	2:14:11	0:00:12	3:28:53	-2	-2	10.48	93	54.5	0.45	0
9	2013-09-06	2:17:47	2:19:02	0:01:15	3:30:08	-2	24	106.97	93	86.4	3.09	0
10	2013-09-06	2:23:52	2:25:16	0:01:24	3:31:32	24	-3	121.08	93	87.7	0.14	0.28
11	2013-09-06	2:25:39	2:27:08	0:01:29	3:33:01	-3	26	129.47	93	88.7	3.72	0.13
12	2013-09-06	2:28:06	2:28:19	0:00:13	3:33:14	26	24	8.56	93	43.4	0.11	0
13	2013-09-06	2:28:19	2:28:20	0:00:01	3:33:15	24	24	8.56	1	43.4	0	0
14	2013-09-06	2:28:35	2:29:49	0:01:14	3:34:29	24	-2	107	94	88.2	0.14	0
15	2013-09-06	2:30:03	2:30:17	0:00:14	3:34:43	-2	-3	14.1	93	62.8	0.07	0.35
16	2013-09-06	2:30:37	2:32:02	0:01:25	3:36:08	-3	24	121.11	93	86.1	3.52	0.17
17	2013-09-06	2:32:26	2:33:43	0:01:17	3:37:25	24	-2	108.13	93	84.7	0.2	0
18	2013-09-06	2:34:38	2:34:53	0:00:15	3:37:40	-2	-3	14.12	93	62.7	0.09	0
19	2013-09-06	2:35:17	2:36:44	0:01:27	3:39:07	-3	25	125.54	93	87	3.61	0.25
20	2013-09-06	2:37:02	2:38:29	0:01:27	3:40:34	25	-3	125.24	93	88	0.12	0
21	2013-09-06	2:38:53	2:40:17	0:01:24	3:41:58	-3	24	121	93	86.4	3.52	0.27
22	2013-09-06	2:43:46	2:45:01	0:01:15	3:43:13	24	-2	107.12	94	86.1	0.15	0
23	2013-09-06	2:45:20	2:45:35	0:00:15	3:43:28	-2	-3	14.17	93	62.4	0.08	0.29
		⁞				⁞			⁞			
657	2013-09-06	17:35:54	17:36:28	0:00:34	1:36:34	19	27	37.76	93	80.9	1.13	0
658	2013-09-06	17:35:55	17:36:46	0:00:51	0:33:55	1	24	70.05	93	84.4	2.73	0.63
659	2013-09-06	17:36:18	17:36:33	0:00:15	1:19:09	-3	-2	14.22	93	58.3	0.71	0.35
660	2013-09-06	17:36:30	17:36:45	0:00:15	1:36:49	27	24	15.86	93	68.8	0.1	0
661	2013-09-06	17:36:49	17:37:11	0:00:22	1:37:11	24	24	5.01	39	14.1	0.22	0
662	2013-09-06	17:36:50	17:37:01	0:00:11	1:19:20	-2	1	8.47	93	47.9	0.42	0.27
663	2013-09-06	17:37:14	17:37:23	0:00:09	0:34:04	24	25	4.28	65	30.5	0.23	0.17
664	2013-09-06	17:37:33	17:37:52	0:00:19	1:37:30	24	18	22.07	93	73.8	0.06	0.13
665	2013-09-06	17:37:44	17:38:28	0:00:44	1:20:04	1	15	60.64	93	84.1	2.03	0.28
666	2013-09-06	17:37:50	17:39:19	0:01:29	0:35:33	25	-3	125.36	94	84.8	0.14	0

Figure 5. Operation history data-set from ELIS

4 Data-Processing for Performance Analysis of Vertical Zoning

4.1 Integration between Activity & Operation DB

The operation pattern of lift operation has deep relationship with work plan of finishing work. Operation pattern can be derived from just moving history like Fig 5. However, it could not handle dynamic pattern changes caused by the birth and death of finishing work activities during whole project cycle unless lift operation plan doesn't reflect each activity's relevant item, lifting frequency. Table 1 shows a case that 55 floor building's lifting frequency record on materials.

Table 1. Case of lifting frequency record (55 floor building)

Lifting item	Lifting Frequency	Ratio (%)
Fire resistive covering	4,913	13.5
Gypsum board	9,583	26.3
Glass	1,632	4.5
Wall Cover	2,533	6.9
Curtain Box	408	1.1
Light Ceiling-Frame	816	2.2
Ceiling Texture	1,207	3.3
FCU Cover	1,309	3.6
Paint	810	2.2
Door & Frame	2,812	7.7
Stone & Frame	918	2.5
Tile Carpet	1,904	5.2
Finishing Material etc.	7,653	21

In order to this study has displayed the operation patterns of the lift in the current process of project in the diagram as shown in the Fig. 6, and made it convenient for a manager to analyze current situations by systemizing data flow. In addition, vertical zoning simulation inputs were utilized.

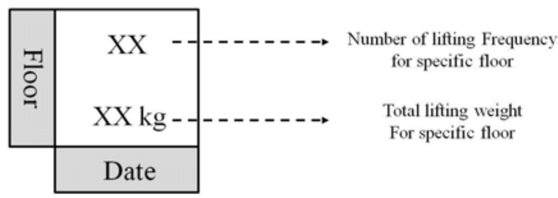

Figure 6. Graphing method for operation history analysis

According to the characteristics of finalizing construction where repetitive processes are vertically connected along with continuity of the work, operation history data module defined as the Fig. 6 can be used as an efficient tool for examination of progress in the present compared to plans by adding objective data-based trend information of a manager on the monitoring of finalizing construction limited to the schedule of finalizing construction.

In finishing work process control, to avoid interference and confliction between finishing work activities some process techniques methods are used such as LOB(Line of Balance) and TACT. Among them, TACT technique has an advantageous to reduce wasting time by confliction. Fig. 7 shows TACT cycle based data composition method.

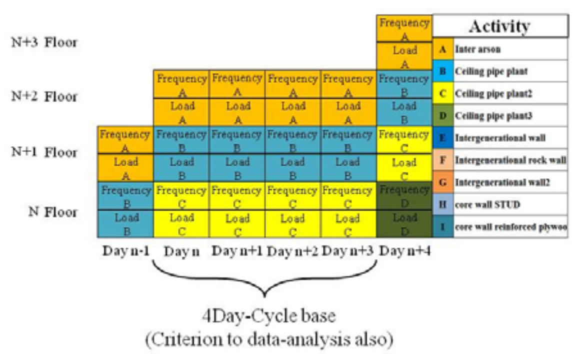

Figure 7. Data composition reflecting TACT-technique

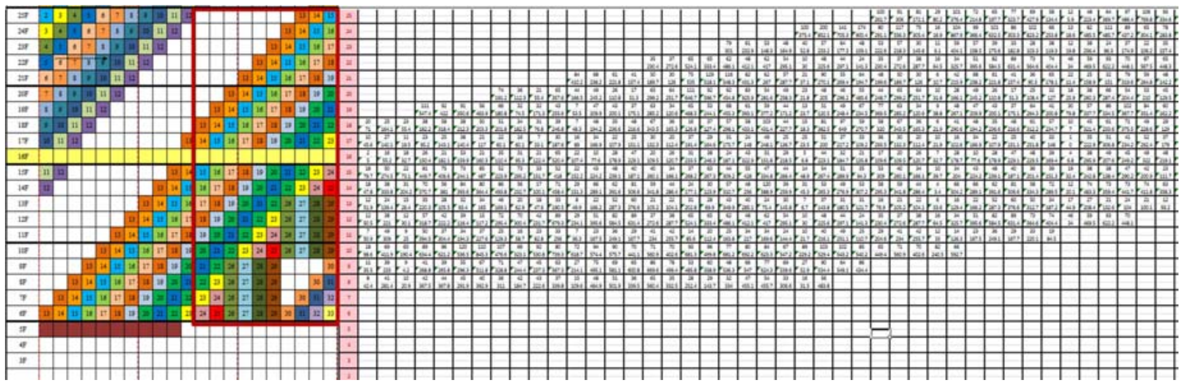

Figure 8. ELIS history data matching to TACT-technique

TACT is performed with the process schedule assuming that all the tact-elements are implemented in the same manner within the consistent cycle. However, a degree of progress in TACT process plans is subject to be changed depending on the work situations in the field. In addition, this is what makes it feasible to find delay factors and modified tact on the plan through operation analytic data and revise them.

Fig. 8 represents the result of matching lift operation records in the field in Korea where ELIS lift operation data system is installed at and tact process schedule in the field. Fields for deriving operation history are the tact process with four-day cycle in principles, and monitoring is performed based on the tact work sheet and tact process minutes. Frequency of operation on each floor and lifting load was setup in accordance with tact format by using the methodology of data in Fig. 6. In addition, a certain format for convenient comparison with a degree of progress for tact process has been derived.

It was analyzed that a progress of finalizing work for core wall side in the field was delayed compared to the plan according to analytic data in Fig. 8. Furthermore, it was confirmed that a schedule of initiating the stud work in the insider wall was made as the tact element number 13. Field manager is able to conveniently identify a progress of tact for finalizing work based on operation record tact data and utilize operation record tact as an index of tact adjustment in the future. Delay factors of tact and issues are reflected on the lift vertical zoning in the field in the future and added on the simulation information based on the date of initiating tact factors.

4.2 Decision Making of Predicting Lifting Event

Generating the predicted lifting event is essential for performance simulation by type of zoning to optimize vertical construction lift zoning. ELIS database is based on data-type of 4×M arrangement. On the row of data arrangement, time, target floor, lifting weight, moving direction linked with storage date are listed. On the column of data arrangement, counted event numbers of specific date are listed through time flow. Fig.9 shows data arrangement of ELIS DB.

	Event 1	Event 2	Event 3	Event 4	• • •	Event M
Signal Time	(1,1)	(1,2)	(1,3)	(1,4)	• • •	(1,M)
Target Floor	(2,1)	(2,2)	(2,3)	(2,4)	• • •	(2,M)
Lifting Weight	(3,1)	(3,2)	(3,3)	(3,4)	• • •	(3,M)
Moving Direction	(4,1)	(3,2)	(4,3)	(4,4)	• • •	(4,M)

Figure 9. Data arrangement on ELIS DB

As shown in Fig. 10, database arrangement described at Fig. 9, algorithm for decision making that able to compute predicted lifting event of next-day. *E* indicates the variable of operation history arrangement stored at ELIS DB. Activity DB stored predicted lifting event information at the time of activity beginning. *A* indicates the variable of predicted lifting data arrangement at the time of activity beginning.

Algorithm for decision making of lifting event prediction needs interaction with manager's recognition about the progress of finishing work because computational algorithm can't check that there is construction delay or not. Hereupon, an input process of variable *n*, *AN(n)* is needed by user.

Compare to last-day, in case that there are additional activities, predicted lifting event has to be added to predicted lifting event arrangement derived from operation history data. And then totally listed event information are re-listed in descending order by time-flow to utilize it as the input data of simulation. *EE* indicates the variable of final predicted lifting event arrangement going to be used on operation simulation. This type of data arrangement is useful to discrete event

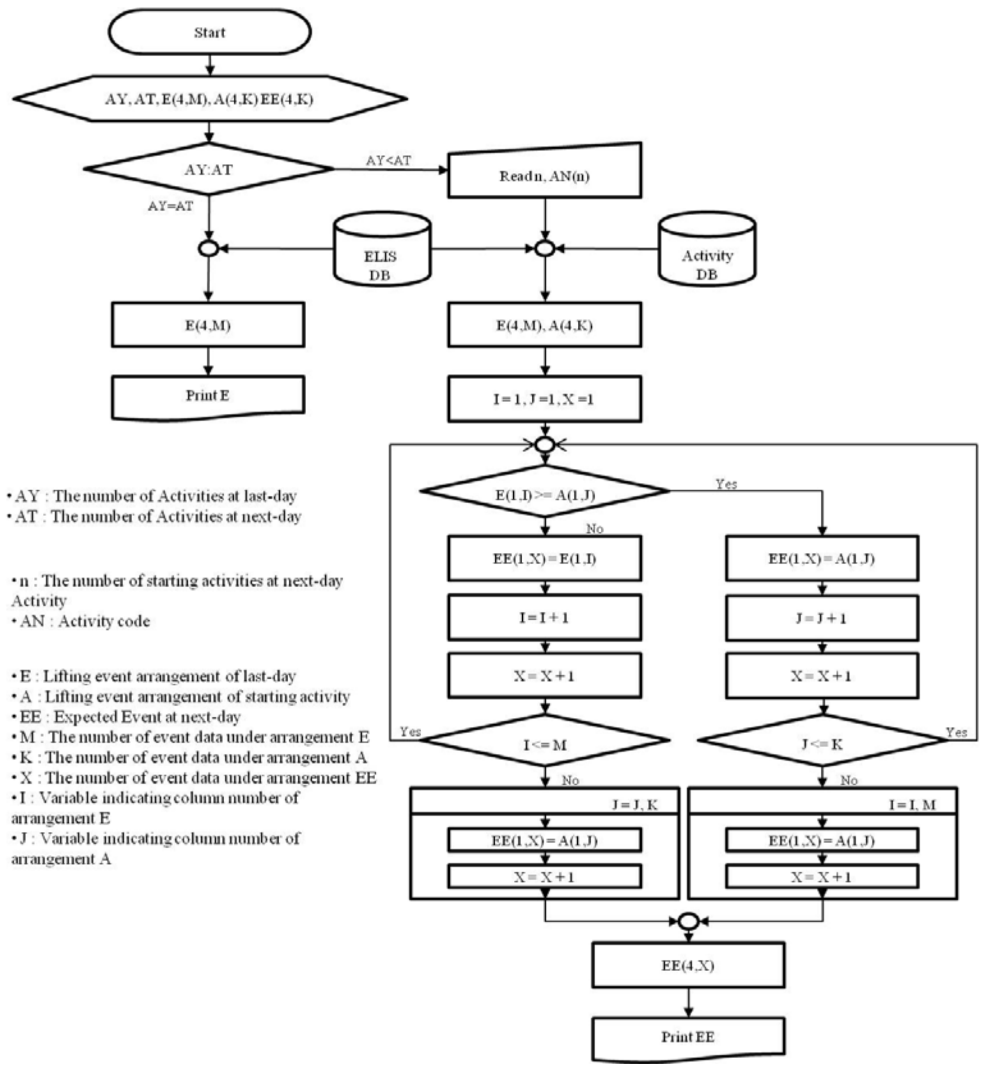

Figure 10. Algorithm flow of decision making for lifting event prediction

modeling based optimization simulation.

Vertical zoning performance simulation for each zoning situation generates many situations by zoning condition of each lift car. As shown in table 2, because each lift car has their own moving section, simulation should compute the result of imaginary operation about lifts in project site.

Table 2. Condition of lift moving section

Situations	Lift A	Lift B	Lift C
Situation 1	1~10	1~20	1 → 10~ Top floor
Situation 2	1~11	1~20	1 → 10~ Top floor
Situation 3	1~12	1~20	1 → 10~ Top floor
⋮	⋮	⋮	⋮
Final Situation	1~ Top floor	1~ Top floor	1~ Top floor

5 Conclusion

As the buildings became high-risen, and the limits on the maximum lifted floors increased, variables applied to the management of finalizing construction became complicated. Hereupon, operation management of the lift is needed for the construction after implementing finalizing process along with a decision-making procedure on the transport-circulation of finishing work materials that are appropriate for flexibly changed situations in the field.

Therefore, in this study, operation history information was saved from sensor modules attached to the lift through development of ELIS(Embedded lift information System), Then it was utilized to draw predicted lifting event using for vertical zoning simulation for future finishing work progress. Based on activity-base process management and TACT technique, we proposed algorithm process for decision making to use an input data on discrete event simulation.

Lastly, this study has served as a starting point of operation system based on the mathematical model and software decision-making process. Therefore, it is anticipated to settle as a system based on unmanned smart lift through verification made in the entire period of research project.

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