Automatic Arrangement Algorithm for Tower Cranes Used in High-rise Apartment Buildings

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Abstract

On most construction sites, the arrangement of tower cranes is decided by site engineers based on their own experience, which can cause cost overruns and delays in the lifting work. Although many researchers have conducted studies on tower crane arrangement using computer modeling and knowledge-based expert systems as well as mathematical models, no research has aimed to develop an algorithm to identify an optimum solution among several alternatives for installation areas of tower cranes satisfying the conditions of lifting work. The objective of this study is to develop an automatic arrangement algorithm for tower cranes used in high-rise apartment construction. First, as a new concept, a possible installation area of tower cranes was suggested. Second, after proposing several alternatives based on the installation points suggested in this study, an algorithm analyzing the economic feasibility of tower cranes was developed considering the rental, installation and removal costs. Third, a case study was conducted to prove the validity of the developed algorithm for selecting and installing an effective set of tower cranes at minimum cost.

Keywords : optimization, lifting, decision support systems, high-rise building

1. Introduction

Worldwide urban development has increased by $940 billion until 2011, and is expected to reach $18 trillion by 2015. In particular, as populations grow in developing countries in Asia, the Middle East and Africa, high-rise apartment projects are rapidly increasing to satisfy housing demands[1]. In South Korea, due to the high population density and lack of available land, many high-rise apartment complexes have been constructed in recent decades. When these complexes are built, the selection and arrangement of tower cranes is generally decided by site engineers based on their own experience. However, as the number of experts is fairly limited and a database for tower cranes regarding lifting capacity, operation properties, rent, etc. has not been widely employed, tower cranes are often not effectively selected and arranged, which can result in cost overruns and delays in the lifting work. Thus, if an algorithm is developed for tower cranes that considers lifting conditions and economic feasibility, experts can establish effective tower crane arrangement and selection plans.

Many researchers have conducted studies regarding the effective selection of tower cranes using computer simulations that provide visual interfaces and databases. In these studies, appropriate tower cranes or available mobile cranes are selected after manually deciding their locations [2,3,4]. In this study, the suggested algorithm

automatically determines the appropriate selection and possible installation areas for tower cranes after determining the weight and installation point of materials, which is different from the method used in previous studies. In other words, in conventional methods, economic feasibility is analyzed after site engineers determine the selection and arrangement of tower cranes, while in this study, an optimum solution is determined after analyzing the economic feasibility of various alternatives for installation areas of tower cranes that satisfy the conditions of lifting work. In addition, with conventional methods, tower cranes could be selected with more than the necessary working radius, which can result in cost overruns, while the method suggested in this study can prevent the selection of tower cranes with an inappropriate working radius because appropriate tower cranes are determined after deciding the working radius.

Therefore, the objective of this study is to develop an automatic arrangement algorithm for tower cranes used in high-rise apartment buildings (A^{3}TC) in order to optimize the arrangement of tower cranes by considering site conditions, lifting capacity, and cost. The algorithm developed in this study can be implemented effectively in a crane arrangement plan on construction sites after being developed as a computer system.

2. Research methodology

This study is divided into four steps to develop A^{3}TC. First, the data of tower cranes are imported into the database. The tower cranes information consists of working radius, lifting capacity, installation and removal cost, and rent. To suggest the possible installation areas, working radius and lifting capacity information are required, and

installation and removal cost and rent are collected to examine the economic feasibility of each CASE. Second, as a new concept, a possible installation area of tower cranes is suggested by analyzing the location where lifting work is required. The mast installation area satisfying the condition of the lifting work is determined by using the working radius of the tower cranes provided from the databases established in this study after determining the weight and installation point of materials. Third, the algorithm is developed to provide alternatives for the selection and arrangement of tower cranes by retrieving the appropriate information of the tower cranes, including working radius, lifting capacity, slewing radius, rent, etc. as shown in Figure 1. Fourth, an algorithm analyzing the economic feasibility of the alternatives is developed that considers the rental, installation and removal costs for each tower crane.

Finally, a case study is conducted to prove the validity of the developed algorithm. This study focuses on the arrangement for tower cranes used in high-rise apartment projects that consist of several buildings. In addition, this study focuses on the luffing and trolley types used in most high-rise building construction.
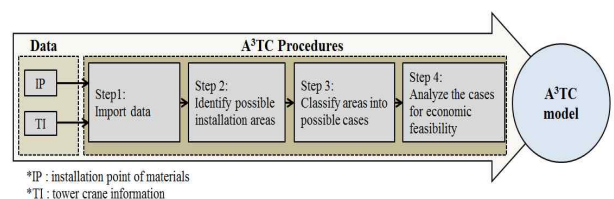

Figure 1. A^{3}TC development procedures

3. Previous studies

In recent decades, many studies have been conducted that aim to optimize the selection and

arrangement of tower cranes on construction sites. The approaches taken in these studies can be classified into three types: computer modeling, knowledge-based expert systems and mathematical models for the arrangement of tower cranes.

First, computer modeling was applied to determine effective selection and arrangement for tower cranes [2,3,4]. Lin and Haas developed an interactive computer-aided process for the optimization of tower cranes by analyzing the factors for decision-making when several tower cranes are planned[4]. Al-hussein et al. provided the arrangement algorithm for mobile cranes based on data including properties and slewing angle for each crane[5]. Huang et al. suggested a computer model for optimum location of tower cranes after selecting the supply point of materials that require lifting work. Although many studies have been conducted on cranes, these studies focused on mobile cranes or the installation of one tower crane[6].

Second, the artificial intelligence approach was implemented to solve complex problems involving uncertainty. Tam and Leung suggested an optimization generic algorithm model for the location of tower cranes by analyzing supply location[7]. Tam et al. developed an artificial neural network model to predict the operation of tower cranes[8]. In addition, some researchers developed models for the selection of tower cranes based on knowledge-based expert systems[9,10].

Third, as a mathematical model, Furusaka and Gray suggested a process for the selection and location of tower cranes considering economic feasibility[11]. However, it was impossible to select an optimum location, as the location of the tower cranes was decided by site engineers, without reliable information. In addition, Rodriguez and Francis suggested a mathematical model for the selection of a location for lifting equipment when a single crane is used[12]. However, it is difficult to apply this to projects using many tower cranes, such high-rise apartment projects.

Although many researchers have conducted studies regarding the selection and arrangement of tower cranes by using computer modeling and knowledge-based expert systems as well as mathematical models, no research has been conducted on the development of an algorithm to identify an optimum solution among alternatives for installation areas of tower cranes that satisfies the conditions of lifting work.

4. Automatic arrangement algorithm

4.1 New concept for tower crane installation

When tower cranes are installed on construction sites, in the conventional method, the appropriate location for a tower crane is determined by analyzing whether or not the working radius included the point required for lifting work. In this study, a new concept is suggested for appropriate tower crane selection and possible installation areas based on the installation point of materials (IP). Here, as the point required for lifting work like the exterior corner of buildings, the installation point of materials is defined as the main point that must be included within the working radius of the tower crane being installed. In addition, it is assumed that the lifting point, the point lifting delivered materials, is always within the working radius of the crane.

As shown in Figure 2, to perform lifting work for IP, the tower crane must be located within 50m of the center of the working radius. In the case of A, B, and C, the lifting work of IP can be performed, while at D the lifting work cannot be conducted, as D is not included within the circle.

Figure 3 represents the concept of a possible

installation area based on the IP concept. In Figure 3 (a), circles describe the area within 50m from points 1, 2, 3, and 4. Area A represents the intersection area of the circles from points 1, 2, 3, and 4, while area B is the area from points 2, 3, and 4. Area C represents the intersection area of points 2 and 4, while points 1 and 3 are not included in area C. Therefore, if points 1, 2, 3, and 4 are assumed to be IPs, to perform the lifting work of four points, the tower crane has to be located in A area, which is the intersection area of the four circles.
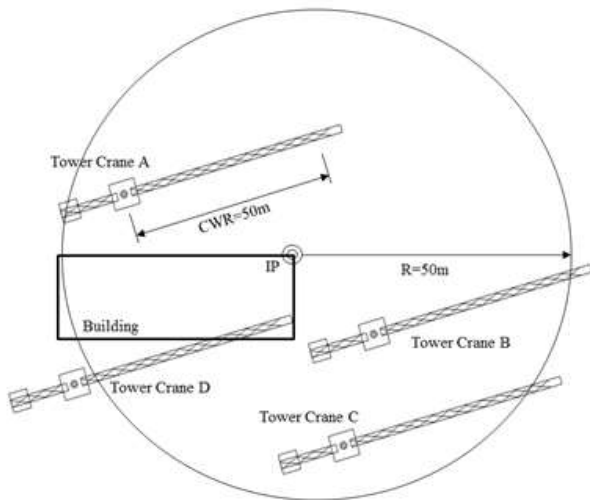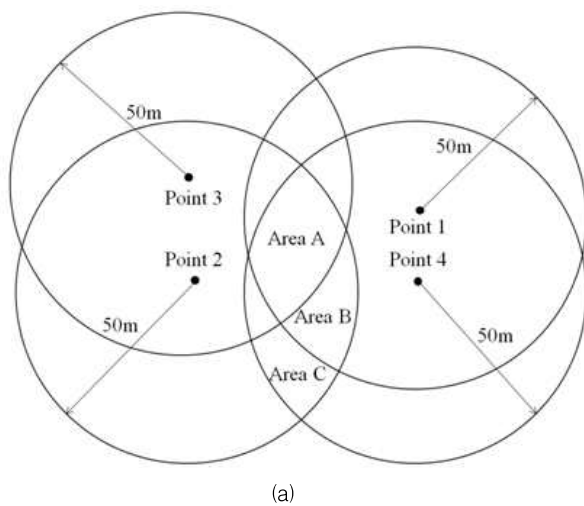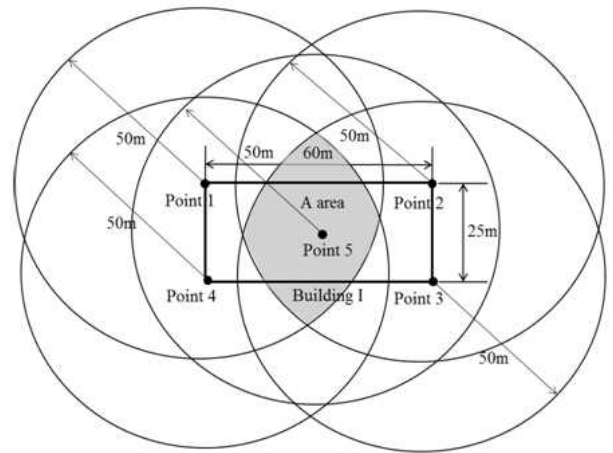

Figure 2. The concept of installation point of materials (IP)

(a)

(b)

Figure 3. The concept of a possible installation area

Points 1, 2, 3, 4, and 5 of building I are the IPs defined in this study as exterior points of the building. Therefore, it can be assumed that all lifting work for building I will be performed if points 1, 2, 3, 4 and 5 are included within the working radius of a tower crane. For example, when a tower crane with a working radius of 50m is installed, the possible installation area is A area, since all lifting work for the five points can be covered from A area, as shown in Figure 3 (b). Therefore, unlike previous studies, the possible installation area for tower cranes can be retrieved based on the IP concept suggested in this study. While the conventional method is convenient when one tower crane is installed for a building, if many cranes are used for a building or several buildings, it is difficult to obtain an installation solution manually since it is a complex challenge to estimate the locations of many tower cranes. However, in this study, the selection and installation of tower cranes can be performed rapidly and accurately by using a computing algorithm for the tower cranes with a working radius satisfying all IPs of the buildings after establishing a database for various tower cranes.

4.2 Tower crane arrangement for multiple buildings

Figure 4 represents the concept of possible areas for the installation of tower cranes for multiple buildings. First, the main points for lifting work are selected based on the IP concept suggested in this study. Second, according to the Crane Working Radius (CWR) retrieved from the tower crane database, circles are created based on the IPs of the buildings. The number of circles created in this process is the same as the IP numbers for the buildings. Third, the possible installation areas are determined by analyzing the intersection areas of the circles.
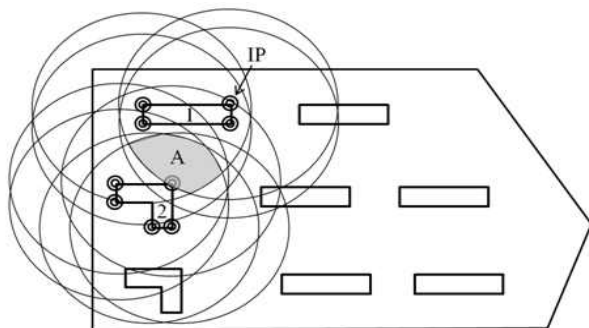

Figure 4. Possible installation area for tower cranes at multiple buildings

The area with the most intersection areas is determined to be the appropriate installation area for the buildings. Finally, the economic feasibility of all available cases of lifting work is analyzed based on the retrieved possible installation areas determined in the previous process.

4.3 Tower crane arrangement for lateral support

When lateral support is required for tower cranes during the construction of a high-rise building, the possible installation area needs to be adjusted, as shown in Figure 5. When the wall bracing method for lateral support is used, the possible installation areas are the areas within 5m of the building, as shown in Figure 5 (a), since the tower crane has to be attached to the building. Therefore, as shown in Figure 5 (b), the areas more than 5m from the building are excluded from the possible installation areas. The area in Figure 5 (b) includes two IPs for lifting work, and B area includes three IPs, while all IPs are included in area C. In this study, the possible installation area for lateral support can be adjusted by using the distance from the building required for lateral support.
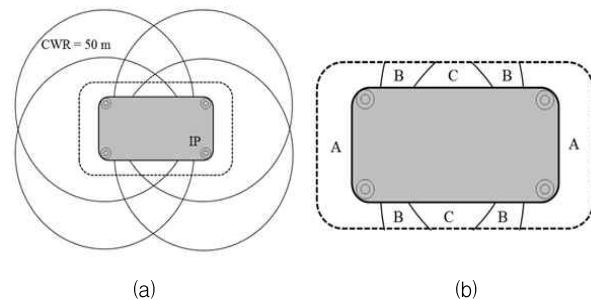

(a)   (b)

Figure 5. Possible installation area of tower cranes when lateral support is required

4.4 Data creation for automatic arrangement

To determine the possible installation area for tower cranes, IP selection has to be considered as the first process. Table 1 represents the information of IPs, which includes coordinates, maximum lifting load, and the start and finish time for lifting work. The coordinates among IP factors are selected by the site engineers or automatically created using the OSNAP function of CAD. When these IPs are created, the proportion of IPs among buildings has to be constant, since the results can be biased if an excessive number of IPs is created in a narrow area.

Table 1. IP Information

Name	X	Y	Lifting Load	Start Time(ST) = Start + month	Finish Time(FT) = Start + month
1	37	46	5	3	25
2	64	93	5	3	25
3	72	16	8	3	27
4	36	74	3	5	27
5	77	79	5	5	29
N	:	:	:	:	:

Tower crane information such as working radius, lifting capacity, installation and removal cost and rent is collected after obtaining IP information. As shown in Table 2, recent tower crane information is imported when the algorithm is performed.

Table 2. Tower Crane Information

Serial Number	Tower Crane	Working Radius (m)	Lifting Capacity (ton)	Installation & Removal Cost (won)	Rent (won /month)
1	KUMKANG KTC7012	30	12	16,000,000	9,000,000
2	POTAIN MD250	30	12	16,000,000	9,000,000
3	LIEBHERR 154HC	30	8	12,000,000	8,000,000
4	LIEBHERR 220HC	30	10	14,000,000	9,000,000
5	LIEBHERR 290HC	30	12	18,000,000	10,000,000

5. Automatic arrangement algorithm process

To develop A^{3}TC, the algorithm is divided into 4 steps: 1) import data, 2) identify possible installation areas, 3) classify areas into possible cases, and 4) analyze the cases for economic feasibility.

5.1 Step 1: import data

The first step of the algorithm suggested in this study is to collect IP and tower crane information. IP information includes coordinates, lifting load, and the start and finish time for lifting work, while tower crane information consists of working radius, lifting capacity, installation and removal cost and rent as shown in Figure 6. The IP and tower crane information is incorporated into Data I.
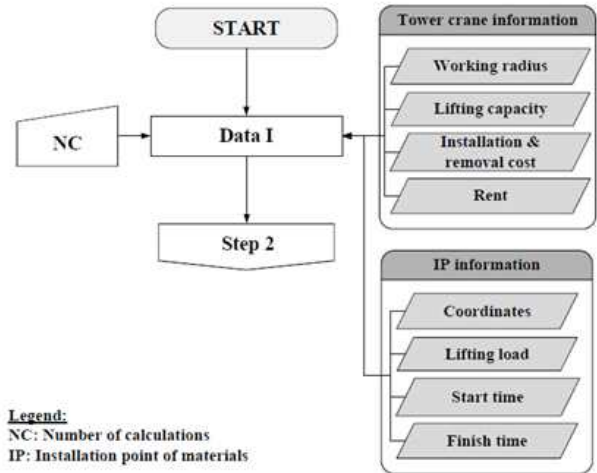

Figure 6. Step 1: import data

5.2 Step 2: identify possible installation areas

In the Step 2, first, according to CWR, one crane of the available tower cranes is selected based on collected IPs coordinates from Step 1 as shown in Figure 7. Second, WR$_{aj}$ is created with its circle having the CWR of the selected tower crane.
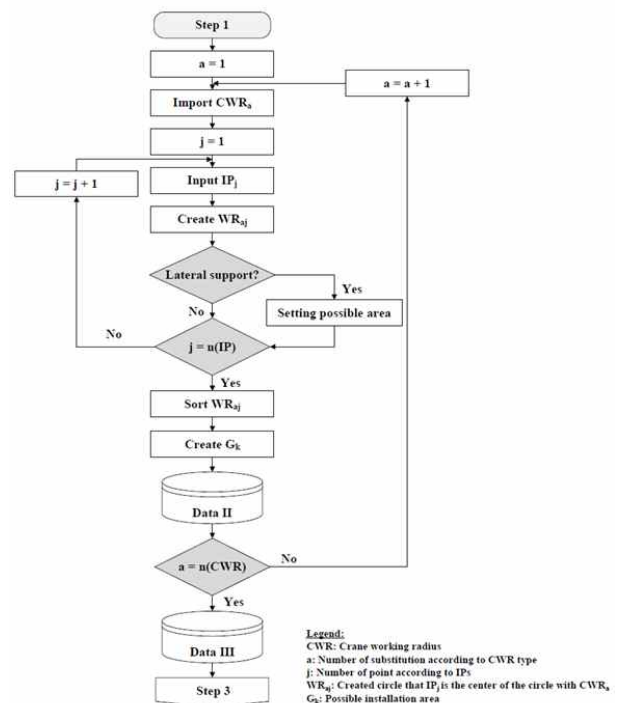

Figure 7. Step 2: identify possible installation areas

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The created WR_{aj} includes IP and tower crane information imported from Step 1. Third, if the building requires lateral support, possible installation areas are identified by analyzing the areas of intersection between WR_{aj} and possible lateral support areas. Fourth, each area of intersection has coordinates of the intersection points, which are imported into Data II, and then installation areas with the most intersection areas are sorted sequentially after WR_{aj} are created at all IPs. The analyzed possible installation areas are defined as a group, G_k as shown in Figure 7. The created G_k is imported into Data II. Finally, all G_k are retrieved by analyzing all available tower cranes by repeating the previous steps, and then are imported into Data III.
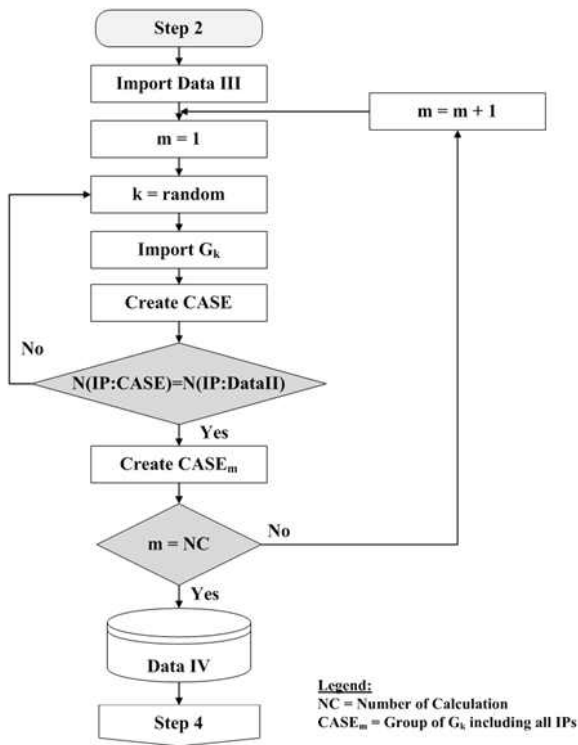

Figure 8. Step 3: classify areas into possible cases

5.3 Step 3: classify areas into possible cases

$CASE_m$ is created in Step 3 based on the possible installation areas (G_k) determined from Step 2.

Each CASE consists of a group of G_k to perform all lifting work that includes all IPs. First, CASEs are randomly created based on collected G_k from Data III. Second, if the created CASE does not include all IPs, the CASE is excluded and the process is repeated. Third, $CASE_m$ that includes all IPs is created the same as the number of calculations entered in Step 1. Fourth, created $CASE_m$ is recorded in Data IV with information obtained from each step, such as CWR, IPs, etc. as shown in Figure 8.

5.4 Step 4: analyze the cases for economic feasibility

The most effective CASE is determined in this step by analyzing the economic feasibility of all $CASE_m$. As shown in Figure 9, $CASE_m$ data is first imported from Data IV. Second, available tower cranes covering maximum lifting load and height are determined according to all IPs of $CASE_m$. Third, from the available tower cranes, an appropriate tower crane satisfying IPs requirements is selected. Fourth, for each CASE, $COST_m$ is estimated, including installation and removal cost and rent.

The rent for the tower crane equals rent per month multiplied by the rent period which is estimated based on the start and finish time obtained from IP information in Data I, as shown in Equation (1). In addition, installation and removal cost is imported from tower crane information included in Data I. Finally, the most economic $CASE_m$ and comparison data of CASEs are printed after estimating $COST_m$ of each CASE. Therefore, as the parameter determining the appropriate CASE according to project characteristics, the COST variable is utilized in this study.

$$COST_m = [\{\sum (FinishTime - StartTime) \times rentCost\} + Installation \& removalCost]$$ ——Equation (1)
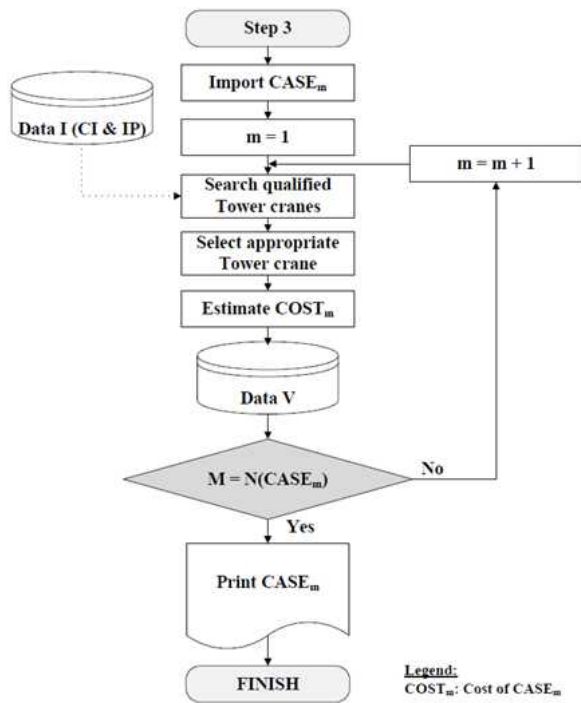

Figure 9. Step 4: analyze the cases for economic feasibility

6. Practical application

To prove the validity of A^3TC developed in this study, A^3TC was applied to a project with four high-rise apartment buildings. Two tower cranes were applied after setting the IPs for four buildings. Table 3 represents information for the two tower cranes (A and B), including working radius, lifting capacity, installation and removal cost and rent. As shown in Table 3, the working radius of A and B was 55m and 65m, respectively.

Table 3. Tower Crane Information of A and B

Serial Number	Tower Crane	Working Radius (m)	Lifting Capacity (ton)	Installation & Removal Cost (won)	Rent (won /month)
1	A	55.0m	6.3	16,000,000	9,000,000
2	B	65.0m	4.8	16,000,000	11,000,000

For tower crane A, circles with radius 55m were created at all IPs of the buildings, as shown in Figure 10, as the working radius of tower crane A was 55m. Through A3TC, it was concluded that a maximum of ten circles were overlapped, which means that lifting work cannot be performed at more than two buildings concurrently, since the number of intersection areas was much less than the number of all IPs (26 points). Therefore, tower crane A was not validated to perform lifting work for the buildings.
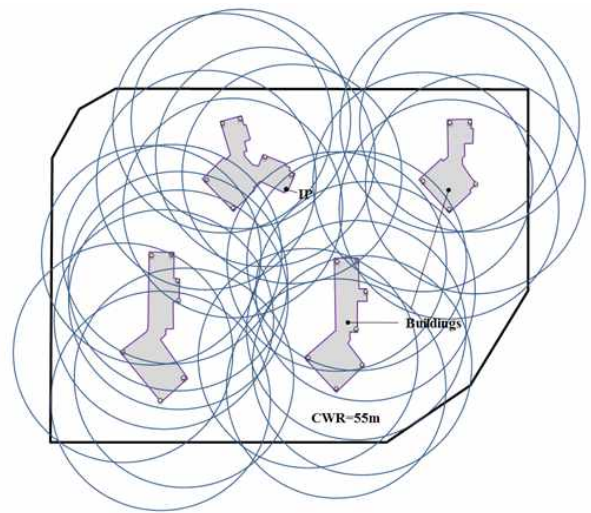

Figure 10. Possible Installation areas for tower crane A

For tower crane B, which had a radius of 65m, as shown in Figure 11, relatively more circles were overlapped. Areas A and B in Figure 11 represent the possible installation area for buildings 1 and 2, respectively. Through the repetitive process of A^3TC, the number of possible installation areas was identified and classified as CASEs to cover all lifting work for the four buildings.

To show the analysis of possible installation areas, areas A–D in Figure 12 represent the areas for performing lifting work for buildings 1 and 2 concurrently, while areas E–H are the possible installation areas for buildings 3 and 4.
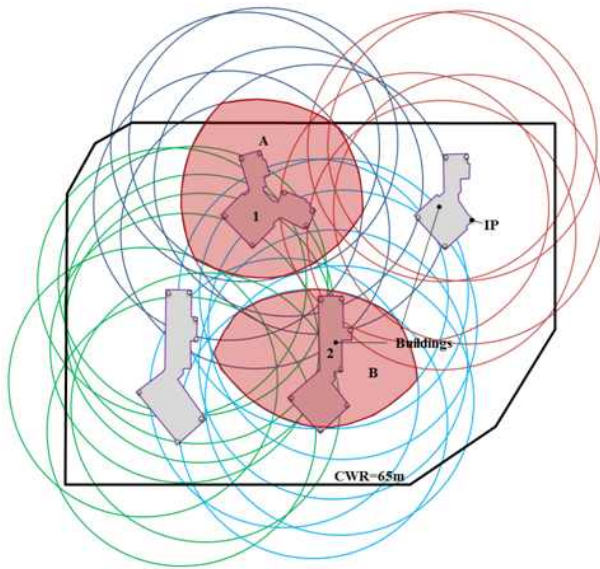
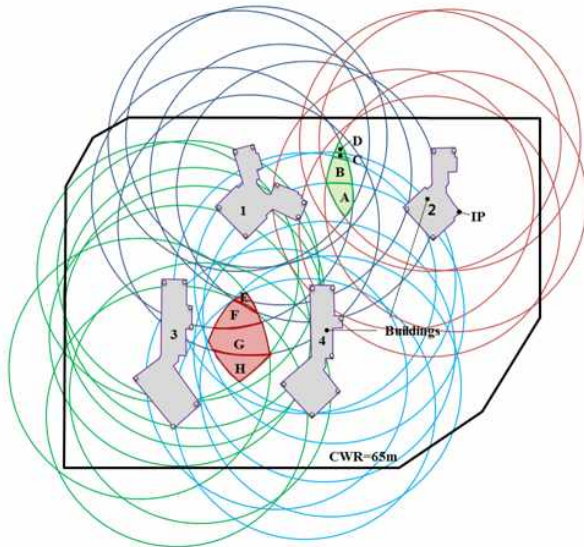Figure 11. Possible installation areas for tower crane B

Figure 12. Analysis of areas A-H for tower crane B

In addition, A area overlapped 15 circles, which means that lifting work can be performed at three IPs in building 4 and at all IPs in buildings 1 and 2. E area also indicated that the lifting work can be performed at five IPs of building 1 and at all IPs in buildings 3 and 4.

As shown in Table 4, H area is the area with the most overlapped circles among the eight possible areas. Since areas A, B, C, and D can

cover the lifting work for buildings 1 and 2, and E, F, G, and H can perform lifting work for buildings 3 and 4, if one area selected from A to D and one area from E to H are combined, all lifting work can be performed. In addition, all CASEs have the same COST because the two tower cranes with 65m working radius are selected. Therefore, it is concluded that A and E CASEs would be the most effective CASEs when tower crane B is selected for the lifting work.

Table 4. Information of areas A-H

Possible area	Coverage	IP (ea)	CWR (m)	Lifting Load (ton)	Cost (Won)
E	3,4	17	65	6.3	110,000,000
A	1,2	15	65	6.3	110,000,000
F	3,4	15	65	6.3	110,000,000
B	1,2	14	65	6.3	110,000,000
G	3,4	14	65	6.3	110,000,000
C	1,2	13	65	6.3	110,000,000
H	3,4	13	65	6.3	110,000,000
D	1,2	12	65	6.3	110,000,000

7. Conclusions

Although many researchers have conducted studies about the arrangement of tower cranes by using computer modeling and knowledge-based expert systems as well as mathematical models, no research has attempted to develop an algorithm to identify an optimum solution among several alternatives for installation areas of tower cranes satisfying the conditions of lifting work. In this study, the objective is to develop an automatic arrangement algorithm for tower cranes used in high-rise apartment buildings.

Traditionally, the selection and installation of tower cranes has been decided based on the experience of site engineers. When the selection and installation is determined on the construction

site, complex projects can experience delays as well as cost overruns in the lifting work, as it is difficult for site engineers to select the appropriate tower cranes. In addition, in the conventional method, the appropriate location of tower cranes was determined by analyzing whether or not the working radius included the point required for lifting work, while in this study, as an IP concept is suggested, potential installation areas are collected accurately and rapidly using the developed algorithm. In addition, it is possible to select appropriate tower cranes in consideration of economic feasibility through A^3TC. Furthermore, the developed algorithm can be applied to commercial buildings and plant projects that use many tower cranes.

In this study, as a pilot study, two tower cranes were used in a case study to verify the developed algorithm. If the program is developed based on the A^3TC proposed in this study, site engineers can select and install appropriate combinations of various tower cranes. Therefore, in future research, the A^3TC program should be developed.

Notation
The following symbols are used in this study:

A^3TC	=	automation arrangement algorithm for tower cranes
IP	=	installation point of materials
NC	=	number of calculations
CWR	=	crane working radius
a	=	number of substitution according to CWR type
j	=	number of point according to IPs
WR_{aj}	=	created circle where IP_j is the center of the circle with CWR_a
G_k	=	possible installation area
$CASE_m$	=	group of G_k including all IPs
$COST_m$	=	cost of $CASE_m$

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