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OPTIMIZATION ALGORITHM FOR AUTOMATIC LAYOUT OF TOWER CRANES

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ABSTRACT: The selection and operation of tower cranes at construction sites are dependent on the personal experience of engineers in charge of lifting work. It often causes to overestimate the safety factor resulting in increase of construction cost, or underestimate it resulting in disastrous accident. Therefore, selection of tower cranes needs to consider cost, safety and maximum lifting condition. This study, for resolving such problems, was intended to propose the algorithm designed for even the inexperienced person to select the optimal lifting equipment in timely manner. The algorithm presented herein is an optimization algorithm that enables automatic arrangement of tower crane and minimization of costs by analyzing such conditions as vertical height and lifting load, etc.

Keywords: Crane location, Tower crane; Algorithm; Optimization; Lifting Equipment

1. INTRODUCTION

1.1 BACKGROUND & PURPOSE

Selection of tower cranes is subject to personal experience and judgment of field manager and tower crane installation engineer in most of construction sites. Selecting tower cranes by experience is likely to compromise operational efficiency in terms of cost, lifting capacity or safety. Capability of tower cranes that performs most of lifting work has significant implication for construction progress and leasing, installing and removing tower cranes in construction site usually requires significant costs. Notably in case of apartment construction projects that typically require multiple tower cranes, selection and arrangement of tower cranes has critical impact on project cost and process management. Against the backdrop, this study intends to develop an algorithm to optimize selection and arrangement of tower cranes.

This study aims to develop an optimization algorithm for automatic layout and selection of tower cranes at large-scale apartment building projects using CAD application.

1.2 REASERCH SCOPE & METHOD

To ensure efficient research and objective conclusion, efficiency, this study limited the scope of research in the following manner. Firstly, target structure was limited to apartment buildings and tower cranes, lifting equipment most extensively used in apartment construction projects, was selected to improve research efficiency. As multiple tower cranes are typically used in apartment construction projects, group of tower cranes need to be arranged in a way to facilitate lifting work on site. Furthermore, given that most apartment construction projects cover a large site area, cost varies significantly, depending on locations and types of mobilized equipment. Therefore, target structure and target equipment herein are limited to apartment building and tower cranes respectively (Fig.1).

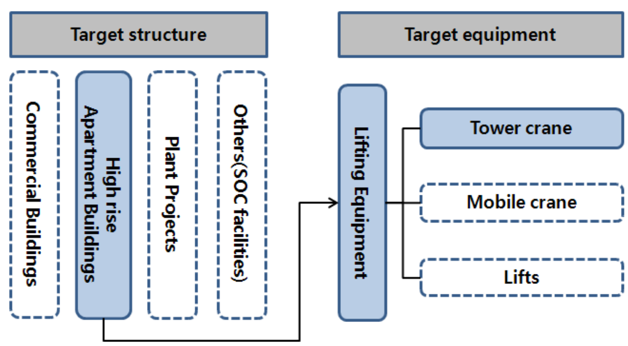

Fig.4. Scope of Research

In terms of the steps of research process, lifting equipment was defined and types and characteristics of lifting equipment were examined by referring to preceding studies. Then, database structure necessary for tower cranes selection was built. To configure building data, coordinates collection method interlinked with CAD application was selected. In the system configuration stage, algorithm to arrange location of tower cranes was built and optimized to enable tower cranes type selection and cost minimization. As the end product of this study, automatic tower cranes arrangement optimization algorithm that factors in location and cost of tower cranes was developed.

2. LITERATURE SURVEY

Data on tower cranes type and operation was examined by referring to preceding studies conducted in Korea and elsewhere to date and limitations of tower cranes selection algorithm were identified to provide reference to development of automatic tower cranes selection optimization algorithm. Firstly, Ho, Jong-Kwan's study in 2007 on optimal tower cranes selection system aligned toward construction site conditions and Park, Jung-Hyun's research in 2003 into a model to select tower cranes location in high-rise building construction project were referenced.

In other countries, more researches on tower cranes selection were available. Shuzo Furusaka's study in1984 focused on optimizing tower cranes selection in consideration of cost implications and presented a process to select location and type tower cranes in the form of algorithm. However, it was still challenging to determine optimal location, as field manager picked location of cranes and conducted review to finalize it. As another reference study of cranes location, Walter E's Single Cranes Location Optimization in 1983 can be cited. His research focused on optimizing location of single cranes and presented a mathematical model to select the location of lifting equipment. However, his model is difficult to apply in large-scale construction sites such as apartment construction sites where multiple number of tower cranes are in operation. Genetic Algorithm for Optimizing Supply Locations around Tower Cranes (C. M. Tom , 2001) analyzed the relationship between tower cranes and nearby supply location and presented a site layout algorithm model. C. M. Tom analyzed the movement of lifting load, which is different from selection of cost-effective tower cranes location. Other studies concerning cranes in construction sites include Optimization Algorithm for Selection and on Site Location of Mobile Cranes(Juan D. Manrique, 2005), Cranes for Building Building Projects(Aviad Shapira, 2007), etc.

3. MODEL DESCRIPTION

Tower cranes selection model consists of 4 steps in total. In Step 1, building edges (outline) and center coordinates are extracted, tower cranes data imported and input number of calculation in CAD application. In Step 2, potential areas where cranes can be situated are identified by finding lifting location necessary for building. In Step 3, areas found in Step 2 are combined to identify combinations that can satisfy all lifting demands in building sites. In the last step, tower cranes type is selected in consideration of lifting load and vertical height among many combinations identified in Step 3 and a combination that can minimize costs including cranes lease charge and installation/removal costs is determined.

4. DATABASE STRUCTURE

4. BUILDING DATA

Algorithm is bound to be loaded heavily, if all areas where lifting is required are entered for analysis in support of tower cranes selection. Therefore, more critical points need to be identified to analyze adequacy of tower cranes location. In this research, building's outer corners, center points and critical lifting locations are expressed as points and such points are referred to as Working Point(WP). If all WPs of building to be built are included in the accessible radius of cranes, the entire building is deemed to be placed within working radius of cranes. Database structure that consists of each WP stores coordinates, maximum lifting load requirement, construction start time and finish time as in Table. 1.

Table. 1. Example of Working Point(WP) Database Structure

Working Point(WP)	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	…	…	…	…	…

4. 2 TOWER CRANE DATA

As for tower cranes information, cranes data used now can be collected in advance and imported when algorithm is run. Tower cranes database structure assigns unique code to each cranes and stores cranes name, Working Radius(WR), lifting ability, establishment and removal costs and monthly rent cost (Table. 2).

Table. 2. Example of Tower Crane Database Structure

Serial Number	Tower Cranes	Working Radius(WR)	Lifting Ability (CPL)	Establishment & Removal Cost(EC)	Rent Cost (RC)
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
N	…	…			

4. 3 TOWER CRANE WORKING RADIUS DATA

Tower cranes radius breaks down into working radius and slewing radius (Fig.2). Working radius refers to radius in which tower cranes can lift load without violating its capacity rating.

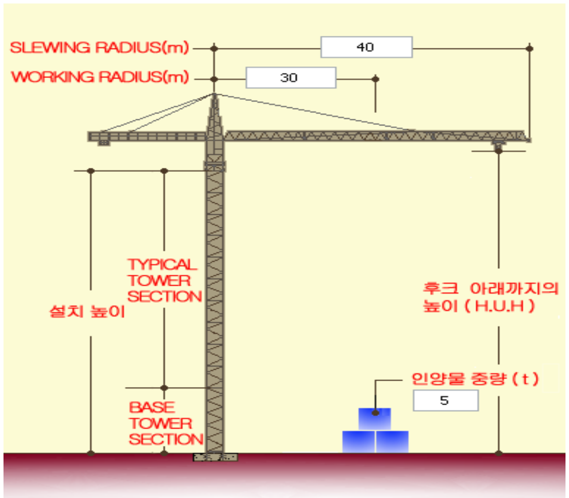

Fig. 5. T-Shape Tower Crane's Working Radius

Crane Working Radius(CWR) data is extracted from available cranes data to enable selection of efficient tower cranes location. Crane Working Radius(CWR) data is a collection of cranes WR extracted from cranes data and CWR is configured in the format shown in Table. 6.

Table. 6. CWR Database Structure

Classification	WR
1	30
2	35
3	40
4	45
5	50
…	…

5. OPTIMAZATION ALGORITHM FOR SELECTION OF TOWER CRANES

5. 1 CONCEPT

Finding locations where to establish tower cranes as a part of tower cranes location selection process requires comparison of numerous data. Furthermore, coordinates of cranes selected in such manner are not significantly different from results produced by conventional approaches in many cases. Simply increasing cases is compromise efficiency of optimization algorithm execution and accuracy of end results. This study intends to identify areas suitable for tower cranes installation in terms of working points rather than select tower cranes coordinates. First of all, range within cranes radius at given working point is identified. Tower cranes installed within such range can perform lifting work at the working point. Fig. 3 shows the installation area of tower cranes. Range within cranes radius from WP is drawn to make a circle with the WP as its center. Cranes installed within the range can perform lifting work at the WP. Tower cranes A, B and C are installed within the 50m semi-radius from WP and their working radius(CWR) is 50m accordingly. Therefore, tower crane A, B and C perform lifting work at the WP. However, tower crane D cannot, as it stands outside the 50m circle from the WP.

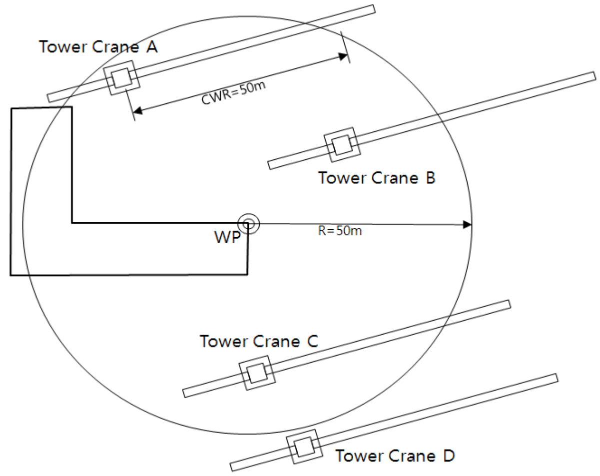

Fig. 6. Tower Cranes Installation Area(CWR=50m)

Installation area where tower cranes can lift load at two WPs can also be found. First of all, one CWR data extracted from available cranes data is selected and a circle with the semi-radius of CWR is drawn with WP as its center. The circle drawn in such manner represents cranes installation area where a cranes whose working radius matches CWR data can perform lifting work at the WP. Intersections of circles drawn from WPs selected in the above manner represent cranes installation area where tower cranes can perform lifting work at WPs that are centers of overlapped circles.

Fig. 4 shows an area where lifting work at 2 WPs can be performed. Circle with 50m semi-radius is drawn from each WP and intersecting area is identified by dotted lines. Tower cranes A installed within the dotted line area with CWR=50 can lift load at two WPs. However, tower crane B located outside the intersection area cannot lift load at the two WPs.

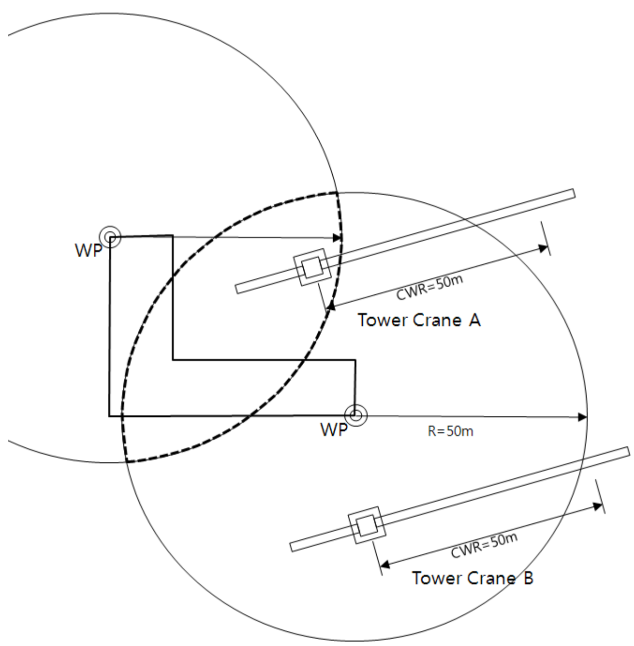

Fig. 7. Intersection between Tower Cranes Installation Areas (CWR=50m)

Area where a single tower cranes can lift load at multiple WPs can be found in the same manner. Fig. 5 illustrates area where tower cranes can perform lifting work at several WPs as necessary. Tower cranes installed in the colored region can lift load at all WPs expressed as dots in the future. In other words, a tower cranes that stands in the area can perform lifting work for both buildings where WPs are created.

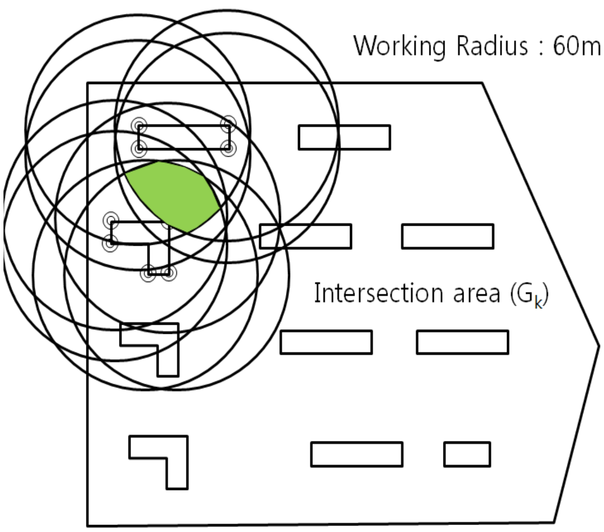

Fig. 5. Selecting Cranes Location using WP & CWR

5. 2 AUTOMATIC WP SELECTION

WP data can be selected by field manager or generated automatically by CAD application. Most design drawings are now produced, viewed or modified by CAD application in most construction sites. When site layout CAD file is opened in CAD application, outline of building and boundary of site are displayed, as CAD SW program provides a function (osnap) that recognizes edges or find center points. Coordinates of edges and center points found in CAD application are imported into tower cranes selection system to generate WP coordinates automatically. It is possible because target structure of this study are apartment buildings. But large size buildings need more WPs.

5. 3 IMPORTING DATA

Terms used in the development of tower cranes selection algorithm are as follows (Table. 3).

Table. 3. Algorithm Terminology

CD = Crane Data (crane type-specific working radius, lifting capacity, rental cost, installation/removal cost data)
WP = Working Point(location where crane needs to satisfy lifting capacity such as outer edge of building)
WR = Working Radius of Tower Crane
NC = Number of Calculation
Layer = A cicle with a WP and the radius of a crane
G_k ($Group_k$)= Intersection area of layers, tower crane installation area
CWR = Crane’s working radius data)
X = x coordinate of WP
Y = y coordinate of WP
ST = WP Start Point
FT = WP Finish Point
C_m = Combination of G_k that can handle all lifting works in site

Step 1 in tower cranes selection system is to import available tower cranes data, CWR data and site Working Point data into the system(Fig. 5).

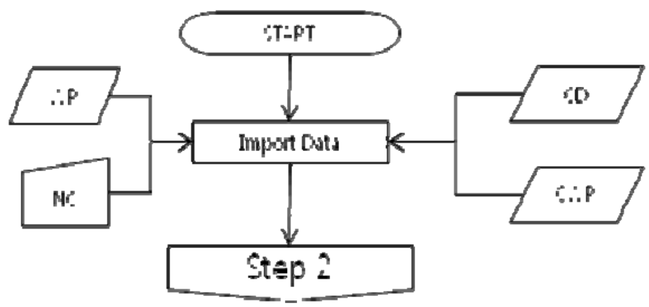

Fig. 8. Step 1

5. 4 GENERATING TOWER CRANES INSTALLATION AREA

Step 2 is to identify combinations of tower cranes installation areas in reference to WP coordinates. First, one WP and CWR data imported in the previous step is extracted. Then, cranes installation area that can support lifting work at the WP is found. Installation area is a circle with WP as center point and CWR as semi-radius. Next, other WP data is entered in sequence to identify and store corresponding installation area respectively. Once installation locations for all WPs are found, intersection between installation area from WP corresponding to each CRW is identified in sequence. As all data search is complete, installation areas, number of intersecting areas and WPs that support lifting work in the areas are stored (Fig. 6).

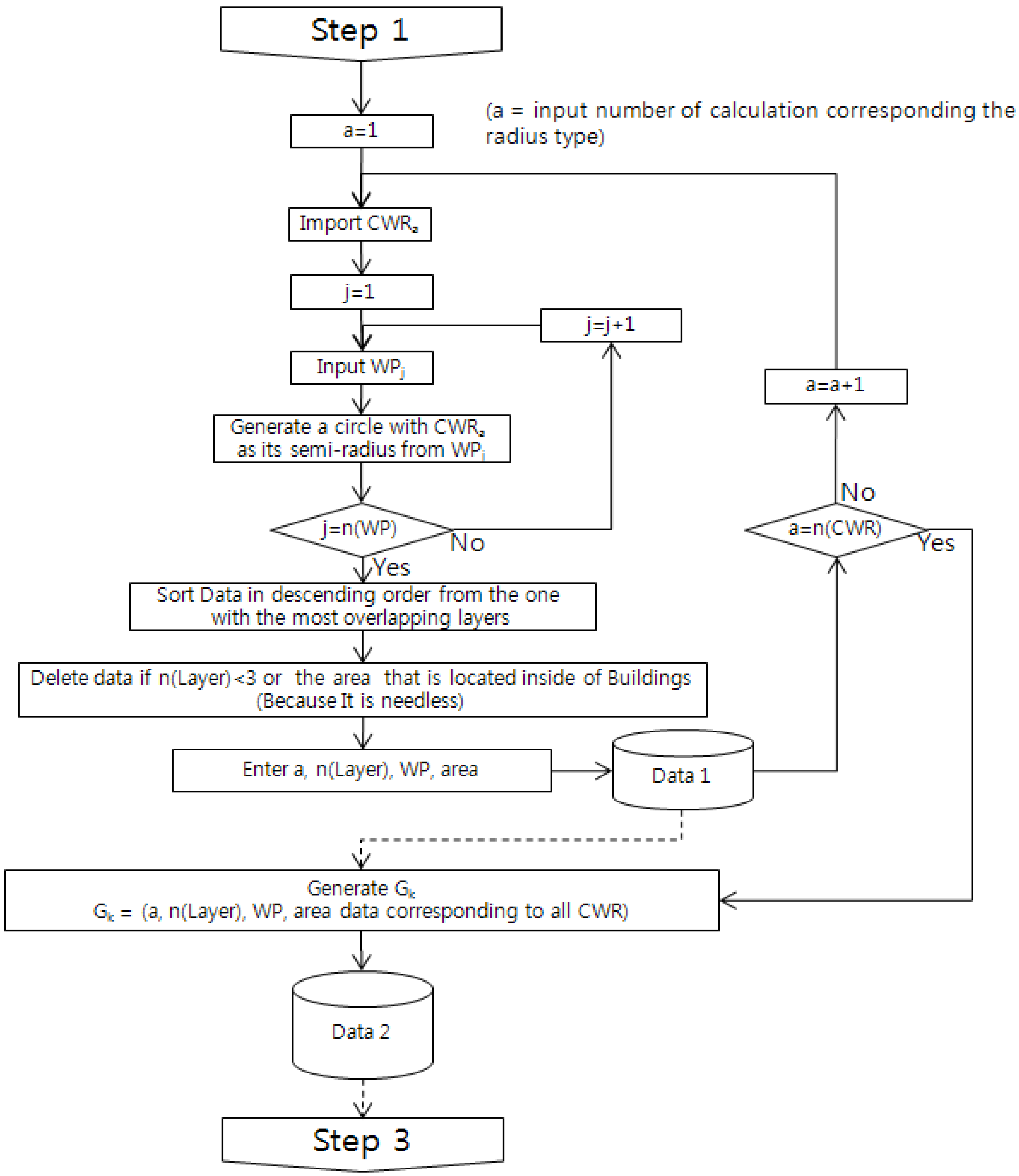

Fig. 9. Step 2

5.5 GENERATING COMBINATION OF TOWER CRANES INSTALLATION AREAS

Installation areas identified in Step 2 are grouped in Step 3. Groups are generated on condition that they encompass all WPs in site. Area data made available in Step 2 includes area coordinates WP data that cranes standing in the area can support lifting work for.

Several combinations of areas can cover all WPs and Step 3 aims to find such combinations. As the group of such combinations cover all WPs in site, it represents an aggregation of tower cranes locations that can support lifting work at all locations in site (Fig. 8). Step 3 generates as many combinations as the Number of Calculation input in Step 1. Such combinations are expressed as C_m in the algorithm. The algorithm applies the group generated in Step 2 to confirm if all WPs in site are covered. If not, different group is applied additionally and it is confirmed again whether all WPs are covered. Such operation is iterated to generate C_m covering all WPs in site and C_m includes the data of groups that constitute itself. Step 3 expires upon generation of as many cases as input number of calculation and hands control over to Step 4 (Fig. 7).

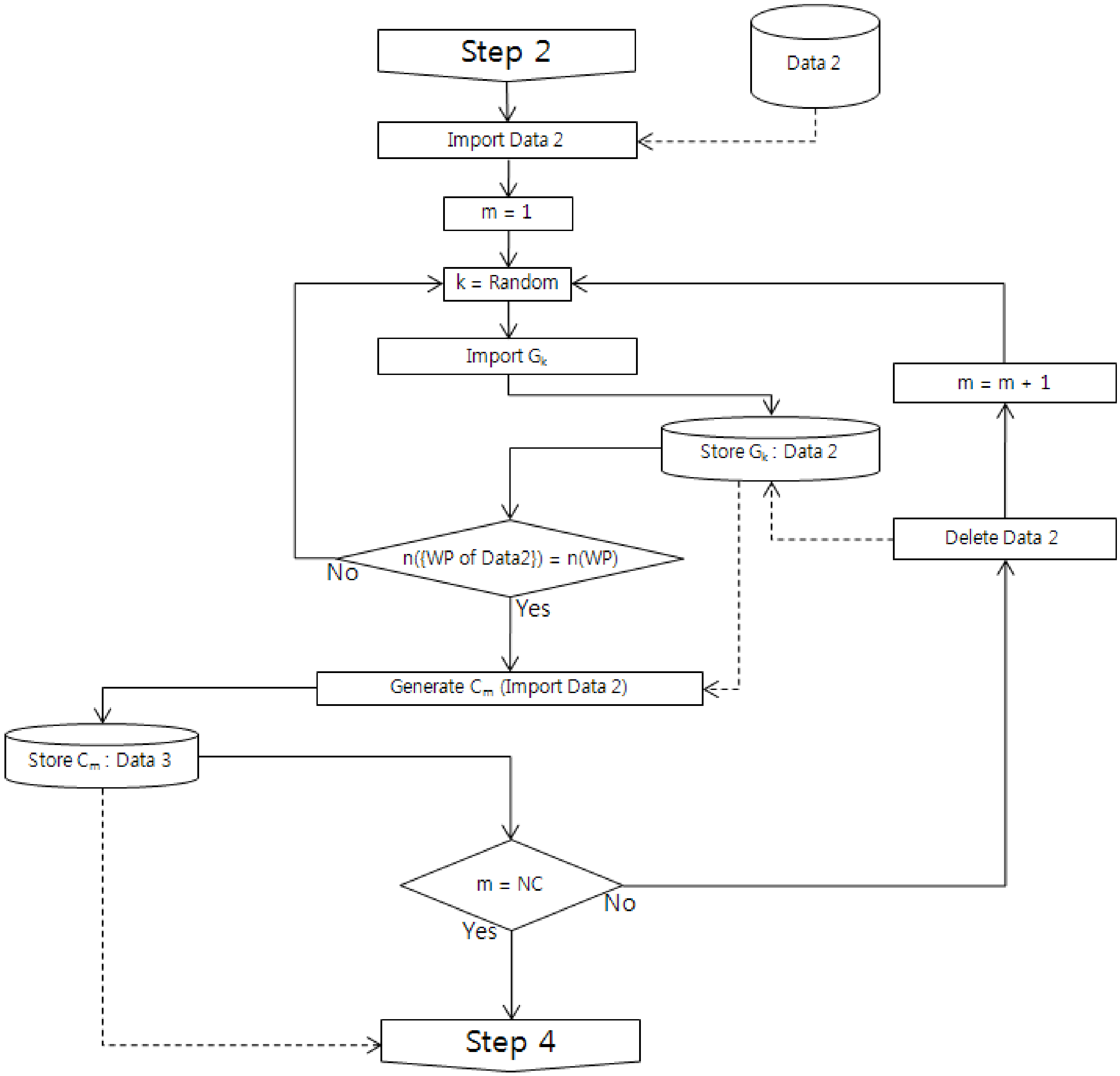

Fig.10. Step 3

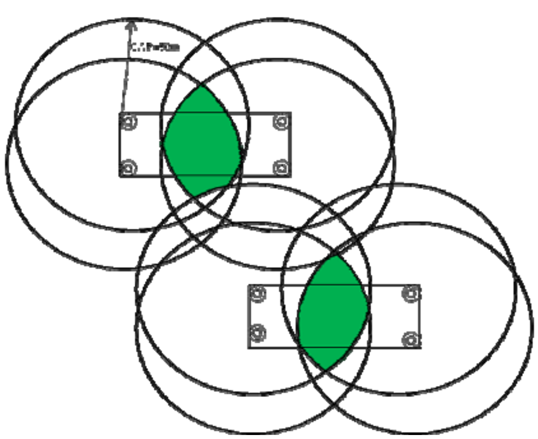

Fig. 8. Generating Combinations of Tower Crane Installation Areas

5. 6 MINIMIZE COST FOR TOWER CRANES

In Step 4, tower cranes data is matched to C_m data to calculate cranes rent cost and establishment/removal costs in site. Group that belongs to each CASE includes WP data and cranes suitable for each group is retrieved from CD via WP data. Suitable cranes herein means a cranes that can lift maximum load to required height at WP at minimum cost. Tower cranes rent cost is calculated by multiplying monthly rent charge in CD data with rent duration from Start Time to Finish Time in WP. In addition, establishment/removal costs can be retrieved from CD data. Once costs of all groups consisting of CASE are estimated, cost of each CASE is calculated. Costs of all CASEs estimated thus far are compared and system is terminated, as the most cost-effective CASE is found and relevant data is printed out (Fig.9).

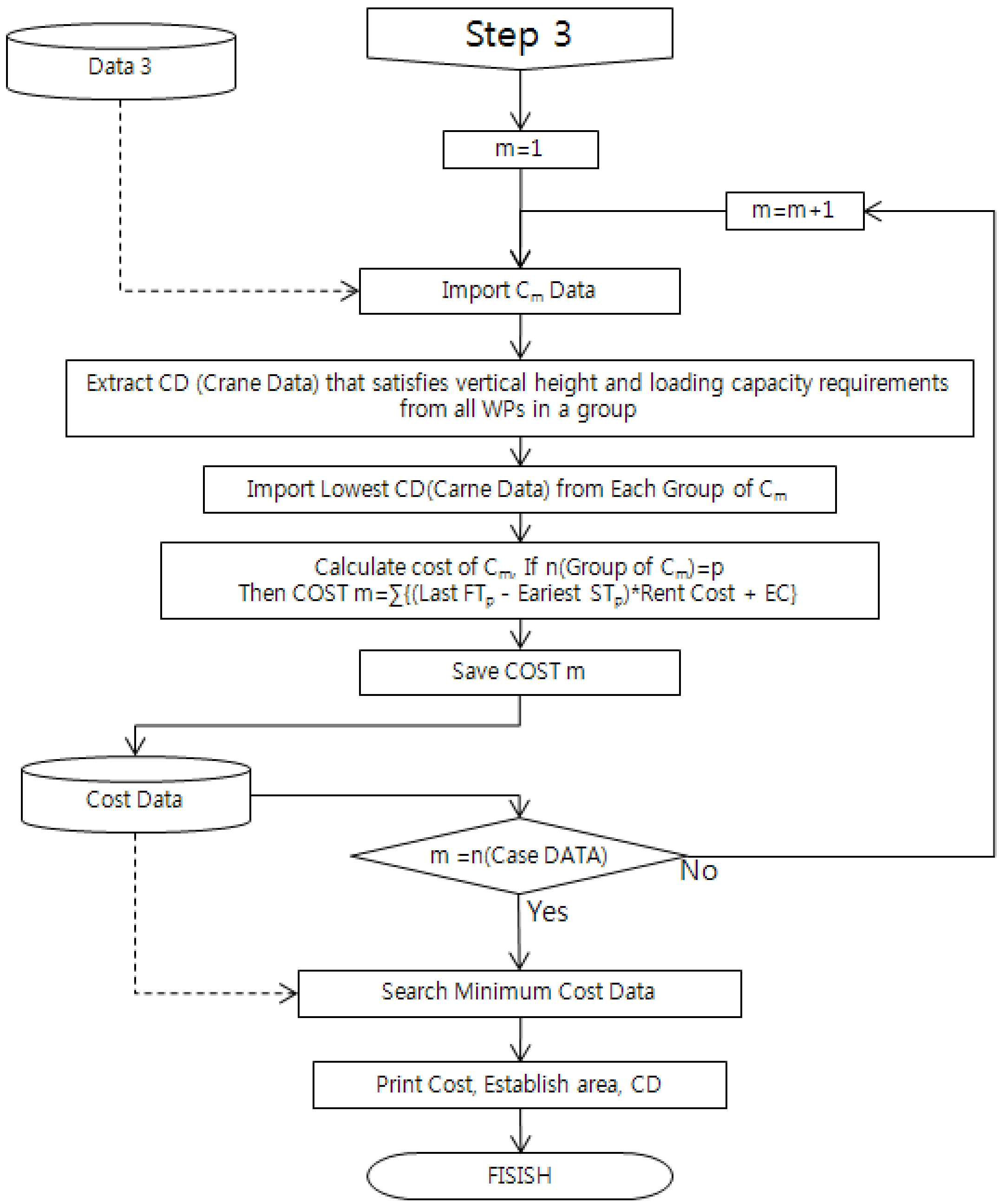
Data 3
Step 3
m=1
m=m+1
Import C_m Data
Extract CD (Crane Data) that satisfies vertical height and loading capacity requirements from all WPs in a group
Import Lowest CD(Carne Data) from Each Group of C_m
Calculate cost of C_m, If n(Group of C_m)=p
Then COST m=∑{(Last FT_p - Eariest ST_p)*Rent Cost + EC}
Save COST m
Cost Data
m =n(Case DATA)
No
Yes
Search Minimum Cost Data
Print Cost, Establish area, CD
FISISH

Fig. 9. Step 4

6. ACCURACY OF END RESULT

Sufficient Number of Calculation is necessary to optimize tower cranes selection in construction site with the algorithm herein. As Fig. 10 shows, end result gets more accurate in proportion to the increase in Number of Calculation. Upon completion of SW system incorporating the algorithm herein, it is necessary to identify minimum number of calculation sufficient to ensure accuracy of end result, subject to the size of construction site.

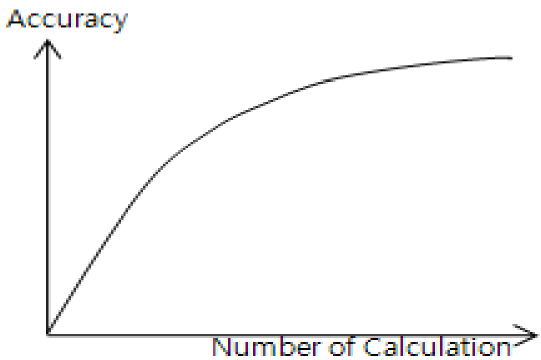

Fig. 10. Accuracy of End Result

7. CONCLUSION

This research proposed an optimization algorithm to support more cost-effective and rational selection of tower cranes in large-scale apartment building project.

First of all, preceding studies of tower cranes selection algorithms were analyzed to identify their limitations in terms of cost-effectiveness and location selection. Then, an algorithm that could minimize tower cranes rent cost and establishment/removal costs in large-scale apartment building project, subject to tower cranes location and type selection. As opposed to conventional approaches, the algorithm was designed to look for intersections of tower cranes installation-ready areas from CWR area with focus on WP. And then, an optimization algorithm was built to minimize costs in consideration of lifting load and vertical height.

When compared to tower cranes selection practice relying on experience of field manager, the algorithm presented herein can reduce lifting cost by enabling more objective analysis. Furthermore, tower cranes can be deployed more in line with site conditions, as their installation locations are expressed in terms of area.

Field manager can use this algorithm system to find optimal tower cranes installation area to deploy tower cranes in site and import available tower cranes data to select optimal cranes type. In addition, more informed decision on tower cranes lifting capacity is expected to prevent selection of significantly smaller tower cranes from resulting in difficulties with lifting work.

As a great deal of cranes data is collected and simulation program is developed subsequently, the tower cranes selection optimization program proposed herein will be used to enable development of more pragmatic cranes selection program in the field.

This paper was performed with supporting of Korea Science and Engineering Foundation by financial resources of government(Ministry of Education, Science and Technology) in 2009 (NO. R11-2008-098-00000-0)

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