A Preliminary Study for Dynamic Construction Site Layout Planning Using Harmony Search Algorithm

Dongmin Lee, Hyunsu Lim, Myungdo Lee, Hunhee Cho and Kyung-In Kang

Abstract Construction site layout planning is a dynamic multi-objective optimization problem since there are various temporary facilities (TFs) employed in the different construction phase. This paper proposes the use of harmony search algorithm (HSA) to solve the problem that assigning TFs to inside of the building. The suggested algorithm shows a rapid convergence to an optimal solution in a short time. In addition, comparative analysis with Genetic Algorithm (GA) is conducted to prove the efficiency of the proposed algorithm quantitatively.

Keywords Site layout planning · Optimization · Harmony search

1 Introduction

Site layout planning is an important task that involves identifying the temporary facilities(TFs) needed to support construction operations, determining their size and shape, and appropriately positioning them within the limited construction space[1]. Such TFs include temporary restaurant, site offices, storage yard, formwork storage yard, storeroom, labor residence, restrooms, utility control room and equipment(e.g., cranes). The site layout problem can be formulated as a assigning of facilities to suitable position over the course of a construction project.

D. Lee · M. Lee · H. Cho(✉) · K.-I. Kang
School of Civil, Environmental and Architectural Engineering, Korea University,
Seoul 136-713, South Korea
e-mail: {ldm1230,iroze00,hhcho,kikang}@korea.ac.kr

H. Lim
Research and Development Center, Yunwoo Technology Co. Ltd.,
Seoul 135-814, South Korea
e-mail: md.lee@yunwoo.co.kr

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Furthermore, the problems associated with the planning of a construction site layout with the consideration of changing site facilities and site space in different time intervals are termed as dynamic site layout problem[2]. In a dynamic site layout problem, finding the optimal time when the temporary facilities are installed and dismantled is a significant factor to improve construction productivity.

On the other hands, according to the recent increase of high-rise building project in the downtown area where the space is very limited for construction, inside space of the building has become a possible allocation area for TFs. This study suggests a new method to solve the optimization problem with harmony search algorithm(HSA) which is one of the most powerful optimization algorithm [3].

Literature reviews show that many models have already been developed using various methodologies such as Genetic algorithm(GA), Ant colony optimization(ACO), Artificial intelligence(AI), computer-aided design(CAD). However, most of the previous researches more focus on static conditions. In fact, the main challenge in developing optimized layouts is in reflecting the dynamic nature of the site over the course of a construction project. Construction activities change as the project progresses, and accordingly, the number and nature of associated objects are subject to change as well. Several TFs enter the site at different times, occupy space on the site for different periods of time, and leave the site when they are no longer required. Furthermore, previously conducted researches.[1, 4-10] only consider horizontal space when generating dynamic layouts even though there is not enough space for the planning in a downtown construction site.

This paper presents an innovative approach based on allowable principles, for the first time, considering the vertical layout planning. In fact, in practically lots of facilities are vertically arranged already on construction site. For example, office is located on 15th floor, storeroom is located on 20th floor, utility control systems are installed every twenty floor in a tall building project in Seoul. This paper recommends an optimization model for vertical layout planning of TFs especially proper for tall building construction site where the space is not enough. At the beginning of the construction, the TFs are allocated or installed on the floor level, and as the buildings are higher, TFs will dynamically be moved to inside of the building. The purpose of the model is to find which floor is best location for each TFs and, when is the best time for movement.

2 Dynamic Construction Site Layout Planning Model

Construction productivity is one of the significant interests in a project. The productivity is related with construction time, cost, and they are all related with site layout plan. The more efficient layout planning, the higher construction productivity according to reduce in working distances. Main movement of laborers are drawn in fig. 1.

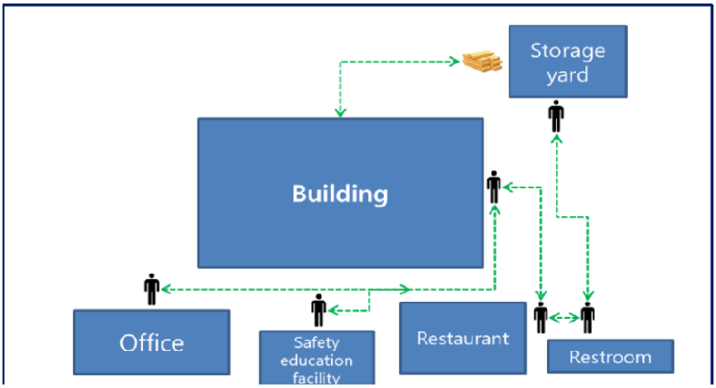


Fig. 1 Main moving path of laborers in construction site

To make a model for vertical layout model for TFs, decision variables are primarily defined. Facilities which can be or should be relocated, and the characteristics of usage patterns for those facilities were identified. According to the facilities, their main roles are different, consequently objective functions are also different each other. Also, even a safety factor is one of the most critical consideration factor when deciding TFs layout planning, by arranging TFs inside of the building, it is no more required to consider the safety factor between facilities since there is no interfere area or hazardous task between them. Therefore, only by minimizing the working distance, construction productivity could be increased until Pareto optimal point.

There are lots of TFs in the construction site and all of them have an intimate relation each other. Furthermore, working distance should be calculated based on the laborer's traffic line or materials transference line, but this paper only takes into account of traffic line of laborers as a preliminary study. Also, the horizontal movement of laborers are not included in the model since it has nothing to do with layout plan. In short, several assumptions are needed in this paper, and they are shown in below.

1. *Working distance is calculated based on the worker's traffic distance.*
2. *Movement of workers can be formulated as an objective function*
3. *Horizontal working distance is not considered when deciding the location of TFs.*

In the proposed model, its dynamic nature originated from the fact that the needed TFs inside of building change as the schedule. To determine the needed TFs in a specific time duration(between any two different tasks, it may could be a cycle time for floor), a three steps approach is used: (1) necessary TFs must be identified and their size should be decided first; (2) a schedule for the construction tasks should be confirmed; (3) each tasks requirements of the TFs are defined, similar to the requirements of labor, equipment etc.

STEP 1. Necessary TFs which need vertical arrangement in the construction site

There are a lot of TFs, but in this study, Temporary Restaurant, Storage Yard, Formwork Storage Yard, Site Office, Lifting Yard, Cement/Sand/Aggregate Storage Yard, Store Room, Labor Residence, Electrical Water and Utility Control room were considered when calculating moving distances.

STEP 2. Analyzing progress schedule and the number of laborers each floor

Progress schedule and the number of laborers should be exactly figured out since it is directly related with working distances.

STEP 3. Modeling of traffic line of laborers

Vertical moving path was mathematically analyzed to calculate quantitatively, the fig. 2 shows a specific case when a temporary restaurant located in 1F and after additional installation inF_k.

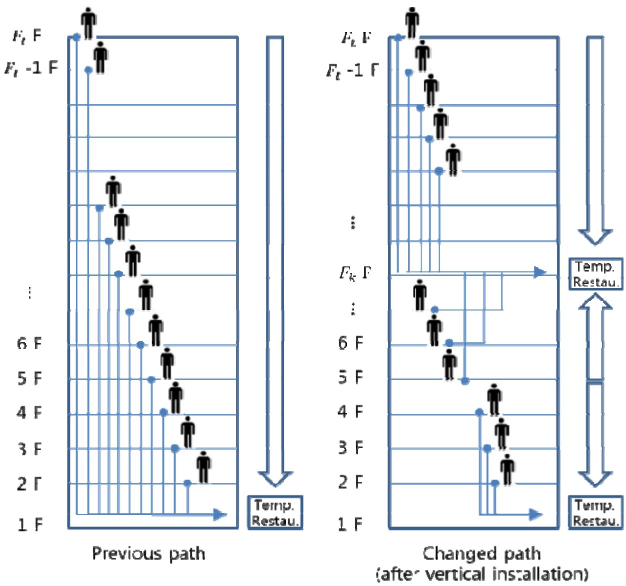


Fig. 2 Traffic line of laborers according to the position of restaurant

STEP 4. Formulate objective function for vertical distance(restaurant)

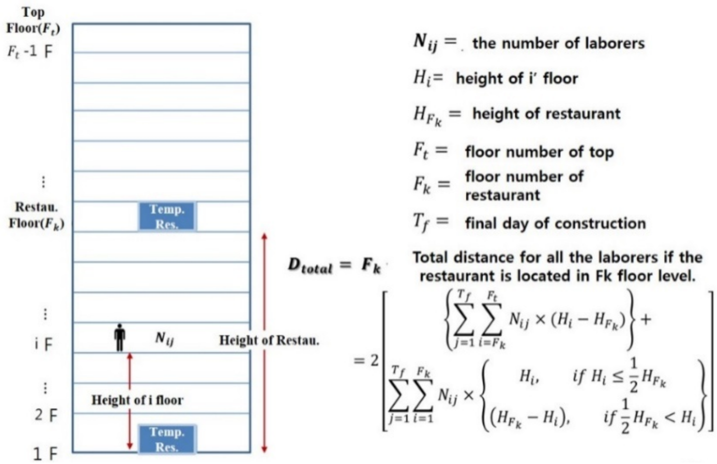
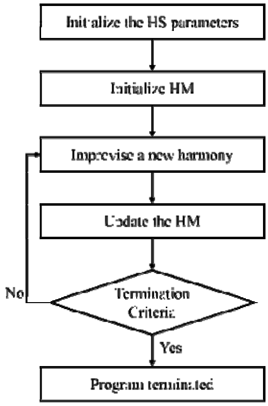


Fig. 3 Vertical distance for the traffic line of workers

In this paper, there are 10 TFs, and they are arranged in a floor level at the beginning of construction stage, and as the buildings getting higher, several or all of TFs are transferred to the inside of building. The optimization process involves the following steps: (1) identifying the time intervals or needed characteristics for the TFs as discussed earlier; (2) identifying facilities' objective function related with worker's working distance; (3) optimizing the location of the selected list of facilities in process or tasks.

3 Harmony Search Algorithm for the Site Layout Problem

There are 10 decision variables(the types of TFs), and each variables' range is 1~50F(assume). Objective function is working distances. The process of placing TFs inside of building uses the HSA which is one of famous heuristic algorithms for optimization problem. Researchers have reported the robustness of HSA and their ability to solve several engineering and construction management problems[6]. The procedure The procedure of HS is shown in below.



(1) Initialize harmony search algorithm parameters.
(2) Initialize harmony memory(HM).
(3) Generate a new harmony.
(4) Update harmony memory.
(5) Check for stopping criterion.

Fig. 4 Harmony search algorithm process

Step 1. Initialize Harmony Search Algorithm Parameters

Initializing to find solution of optimization problem. Size of decision variable, and their minimum, maximum value selection. Adjusting Harmony Memory Size(HMS), Harmony Memory Considering Rate(HMCR), Pitch Adjusting Rate(PAR), Iteration number. The HMCR value generally 0.7~0.9, and PAR is 0.2~0.5. The parameter value used in another researches are shown in below.

Table 1 HSA optimization parameter in other studies

Researcher	HMCR	PAR	HMS	NI
Mahdavi et al (2007)	0.95	0.35~0.45	4~7	3,000~300,000
Kang et al (2004)	0.85	0.3~0.45	10	50,000
Vasebi et al (2007)	0.8	0.5	6	30,000
Pan et al (2010)	0.9	0.3	5	50,000
Geem (2007)	0.95	0.05	30	30,000

Step 2. Initialize harmony memory(HM)

As shown in eq.(1). Harmony memory is in the form of the two-dimension matrix(HMS)$\times$ $(\mathrm{N}+1)$, where each solution vector plus objective function value are kept inside.According to the random generation, the HM is initialized. Also, predetermined constraints conditions are check in this stage, and by giving penalty for them, bad solutions are deleted from the HM. At the end of this process, the HM contain optimal or near optimal solution vectors.

$$\mathrm{HM} = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_{N-1}^1 & x_N^1 & f(x^1) \\ x_1^2 & x_2^2 & \cdots & x_{N-1}^2 & x_N^2 & f(x^2) \\ \vdots & \cdots & \cdots & \cdots & \cdots & \vdots \\ x_1^{HMS} & x_2^{HMS} & \cdots & x_{N-1}^{HMS} & x_2^1 & f(x^1) \end{bmatrix} \quad (1)$$

N: number of decision variable
HMS: harmony memory size

Step 3. Generate a new harmony

A new harmony memory vector$x' = (x_1', x_2', \cdots, x_N')$is generated form the HM based on the HM consideration, random selection, pitch adjustment. For instance, the value of first decision variable (x_1') for the new vector can be chosen from any value in the HM range$(x_1^1 \sim x_1^{HMS})$. And the other decision variables also can be chosen with same rule. There is a possibility that the newly generated value can be chosen using HMCR rule, and that varies between 0 and 1 as follows:

$$x_i^{new} = \begin{Bmatrix} \{x_{i,1}, x_{i,2}, \cdots, x_{i,hms}\} \text{ with probability } HMCR \\ \{x_1, x_2, \cdots, x_N\} \text{ with probability } 1 - HMCR \end{Bmatrix} \quad (2)$$

The HMCR sets the rate of choosing one value from the historic values stored in HM, and (1-HMCR) sets the rate of randomly choosing one value from the entire possible domain. For instance, a HMCR 0.9 indicates that the newly generated value is chosen from the HM with a 90% probability and from the entire domain with a 10% probability. Every component obtained from the memory consideration is examined to determine whether it should be pitch-adjusted.

$$x_i^{new} = \begin{Bmatrix} Yes \text{ with probability } HMCR \\ No \text{ with probability } 1 - HMCR \end{Bmatrix} \quad (3)$$

The value of (1-PAR) sets the rate of doing nothing. If the pitch adjustment decision for x_i' is YES, x_i' is replaced as follows.

$$x_i' \leftarrow x_i' \pm rand(\quad) * bw \quad (4)$$

Where

bw is an arbitrary distance bandwidth
rand() is a random number between 0 and 1

Step 4: Update harmony memory

If newly generated harmony vector $\boldsymbol{x}^{\boldsymbol{new}}$is better than worst harmony$\boldsymbol{x}^{\boldsymbol{new}}$ in HM(the evaluation is based on fitness function), then exclude $\boldsymbol{x}^{\boldsymbol{worst}}$from the HM. As a result, HM will be updated with better solutions as the iteration keep going.

Step 5: Check for stopping criterion

Repeat Step 3 and 4 until stopping criterion the criterion could be a certain time or number of iteration(NI). this paper used NI=1500

4 Numerical Experiments(Comparative Analysis Between GA)

4.1 Description of Case

The case site is 50th floor building, and 10 different facilities must be assigned to inside of the building. Numerical experiments are conducted to justify the proposed optimization model. Also, comparison between GA was conducted to show the efficiency of HSA. After applying HSA and GA at the same example case, the solution was quantitatively analyzed.

Table 2 Decision variables and its volume(assume)

Num	Facilities	Volume(m^2)
1	Temporary Restaurant	750
2	Storage Yard	800
3	Formwork Storage Yard	950
4	Site Office 1	1,000
5	Site Office 2	1,000
6	Lifting Yard	900
7	Cement, Sand, Aggregate Storage Yard	820
8	Store Room	1,300
9	Labor Residence	850
10	Electrical Water and other Utilities Control Room	980

Table 3 The height of each floor and their volumetric constraints(assume)

Floor Num	Height(m)	Volume(m^2)
1	6	1,500
2	12	1,300
3	18	1,200
	⋮	
48	210	1,200
49	214	1,000
50	218	800

Table 4 The distance calculation formula of each facilities(assume)

Num	Facilities	Distance Calculation Formula
1	Temporary Restaurant	$\sum\sum_{i=1}^{F_k} N_i * (H_i - F_i) + \sum\sum_{i=f_k}^{50} N_i * (H_i\ or\ H_k - H_i)$
2	Storage Yard	$\sum_{i=1}^{50} 2 * (i - F_i) * N_i$
3	Formwork Storage Yard	$(50\text{-}F_i)*N_{50}+(49\text{-}F_i)*N_{49}+(48\text{-}F_i)*N_{48}$
4	Site Office 1	$(50 - F_i) * N_t * 3.5 * 2 + F_i * N_n$
5	Site Office 2	$(50 - F_i) * N_t * 3.5 * 2 + F_i * N_n$
6	Lifting Yard	$\sum 2 * (F_i - F_{i-1})$
7	Cement, Sand, Aggregate Storage Yard	Better near N_{10}, N_2 farN_1
8	Store Room	$\sum 2 * (F_i)$
9	Labor Residence & Restroom	Distance between Restaurant and Labor Residence, Restroom
10	Electrical, Water and other Utilities Control Room	Summation of distance to another facilities position.

- ***Constraints (Hard)***

1. Total installed volume of facilities in any floor must be less than the maximum space of the floor.

- ***Constraints (Soft)***

1. Restaurant cannot be installed at the top floor.
2. Restrooms and Labor residence should be installed near one of offices.
3. Utility Control Systems should be installed lower than 25^{th}

- ***Optimization Parameter set***

Optimization Parameter	Value
HMCR	0.1, 0.5, 0.8
HMS	15, 50
PAR	0.1, 0.5, 0.8
Crossover probability	0.5, 0.8(Optimum)
Population Size	15, 50
Mutation probability	0.2(optimum)
Stopping criterion	500, 1000, 1500

4.2 Results

These tables are comparison between GA and HS.

Table 5 Optimum solution using HS

Facilities	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
Floor	22	25	11	1	14	11	18	2	10	9

Table 6 Optimum solution using GA

Facilities	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
Floor	23	26	25	1	49	27	50	2	24	3

In a 50th floor building, each facilities should be installed when starting construction of the i floor. For example, X_5 is Office, and to minimize the total distance of laborers, the office should be installed when 14th floor construction is finished (In HSA).

Table 7 Comparison between HMS and GA

<table>
<tr><th>HMS</th><th>HMCR</th><th>PAR</th><th>Iteration</th><th>Objective Function (HS)</th><th>Objective Function (GA)</th></tr>
<tr><td rowspan="9">15</td><td rowspan="3">0.8</td><td rowspan="3">0.8</td><td>500</td><td>53012 km</td><td rowspan="18">53834 km
Minimum at
(NI=1500, CR=0.5, M=0.2)
54110 km
Minimum at
(NI=1500, CR=0.8, M=0.2)</td></tr>
<tr><td>1000</td><td>52893 km</td></tr>
<tr><td>1500</td><td>52809 km</td></tr>
<tr><td rowspan="3">0.5</td><td rowspan="3">0.5</td><td>500</td><td>54152 km</td></tr>
<tr><td>1000</td><td>52800 km</td></tr>
<tr><td>1500</td><td>52781 km</td></tr>
<tr><td rowspan="3">0.1</td><td rowspan="3">0.1</td><td>500</td><td>55181 km</td></tr>
<tr><td>1000</td><td>54036 km</td></tr>
<tr><td>1500</td><td>53383 km</td></tr>
<tr><td rowspan="9">50</td><td rowspan="3">0.8</td><td rowspan="3">0.8</td><td>500</td><td>54387 km</td></tr>
<tr><td>1000</td><td>53451 km</td></tr>
<tr><td>1500</td><td>54113 km</td></tr>
<tr><td rowspan="3">0.5</td><td rowspan="3">0.5</td><td>500</td><td>54099 km</td></tr>
<tr><td>1000</td><td>53451 km</td></tr>
<tr><td>1500</td><td>53069 km</td></tr>
<tr><td rowspan="3">0.1</td><td rowspan="3">0.1</td><td>500</td><td>53276 km</td></tr>
<tr><td>1000</td><td>52907 km</td></tr>
<tr><td>1500</td><td>52675 km</td></tr>
</table>

In HMS=50, if the HMCR and PAR are higher, the objective function is increased

In HMS=15, if the HMCR and PAR are higher, the objective function is decreased

In the same HMS, HMCR, PAR condition, If the NI is increased, then the objective function continuously decreased. (Better result)

The best result, came from the GA, was **53,834km** and the best results came from HS were **52,781km(HMS=15, HMCR=0.5, PAR=0.5)** and **52,675 km(HMS=50, HMCR=0.1, PAR=0.1)** each. That means HS is better Algorithm than GA for this optimization problem within 1500 iteration.

5 Conclusion

The objective of this study is to provide a methodology for developing dynamic, vertical layout planning that are optimized over the duration of the project, while reflecting the actual changes on the site, in terms of object requirements and relationships between objects and their unique objective function which is made based on laborer's working traffic lines. The HSA was utilized to solve the problem. On the other hands, vertical layout can be conceptually viewed as a problem in which a multitude of objects, with different temporal and spatial dimensions, and different proximity relationships, compete over best locations in a given space.

A key feature of the model is that it considers the actual duration for which objects are required on the site in the process of optimization. This feature enables the reuse of the same space by different objects over the course of time. Furthermore, previous approaches are only focused on horizontal layout planning and they are not any meaning in the tall building projects since there is no space in horizontally. Another important aspect of the model is that it allows for a simultaneous search for the optimum location of all the objects that are required in different periods of the project. In other words, it allows all objects, regardless of the time and order in which they arrive on the site, to have an equal chance to compete over optimum locations for the specific time that they are required on the site.

5.1 Limitation and Further Study

The stopping criterion was set to be a 500, 1000, 1500 to investigate the efficiency of algorithm in a very short time(only 0.3sec searching time could be vulnerable to probability terms). Also, this model only considered 1day working distance, so it could not guarantee that is a global optimum, broader investigation is required.

Even though there are lots of TFs which should be considered when site layout planning, only 10 facilities are considered. Therefore, the decision variables should be more various. Also, parameter optimization was not conducted enough, more experiments and more realistic modeling is required.

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