# Facility Layout Problem with Genetic Algorithm

## Genetic Algorithm을 이용한 건설물자재의 Layout

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### Abstract

The most commonly used method for space management in the industry is development of site plans. These plans outline how to manage material deliveries, staging areas, and crane locations for construction sites in suburban area but not in congested urban areas. This study focuses on how to efficiently manage space for construction facilities on high-rise buildings in congested urban areas where normally space for facilities around a building footprint is not available. The limitations of available horizontal space create a need to explore vertical expansion of facilities. This raises new aspects of vertical facility handling and flow that need to be considered in the facility design problem. The construction facilities layout plan method provides layout planners with a valuable technique to develop efficient sequences of work that optimally defines how to efficiently utilize the construction facilities and minimize the travel of specific facilities effort on multiple-floor buildings. A genetic algorithm-based heuristic will be presented for generating block layouts for multiple-floor layout problems.

**Keywords: Construction Facilities, Layout problems, Genetic Algorithm**

## 1. Introduction

Construction facilities should be stored so they are accessible when needed. Facilities storage area should be selected carefully to avoid impacting construction operations, and facilities procured by the general contractor should be inspected upon delivery to ensure that the correct items and quantities were delivered. However, like any resource, the amount of construction site space demanded by the various activities changes with the schedule of the work. Therefore, as the schedule evolves during the project, the site layout may need to be efficiently re-organized at various intervals to satisfy the upcoming schedule requirements to maintain construction site productivity. (Emad et al. 2001).

## 2. Problem Statement

A time-space conflict occurs when an activity's space requirements interfere with another activity's space requirements or with work-in-place, and it affects the performances of interfering activities. Space and time conflicts have been identified as one of the major causes of productivity loss in construction [Ahuja and Nandakumar (1984); Kuntz (1994) Oglesby, Parker et al. (1989) Rad (1980) and Sanders, Thomas et al. (1989)]. Sanders, Thomas et al. (1989) stated that efficiency losses of up to 65% are due to congested workspace and up to 58% are due to restricted access. Howell et al. (1993) reported the elimination of sharing resources, such as work areas, as a first step for performance improvement at construction sites. Especially when a site is very tight or highly constrained such as construction in an urban environment or facility rehabilitation.

To evaluate facility handling satisfaction, a survey was performed by Jang (2002). The survey asked project manager about the quality of raw materials (right things),material positioning of temporary facilities on a jobsite, and unnecessary movement of materials and equipment (Figure 1).

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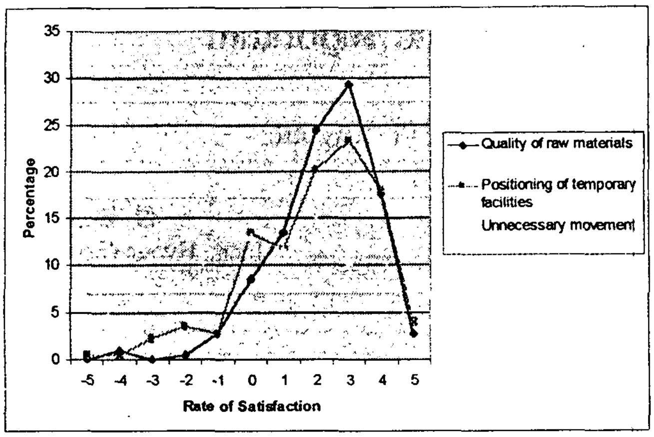


Figure 1: Satisfaction of Material Flow

The quality of raw materials (right things) and material positioning of temporary facilities on jobsite satisfaction rate defined each 29.2 and 23.3 percent at third satisfaction level but most project managers have very unsatisfied with the unnecessary movement of materials and equipment.

## 3. Related Research

Recent research has focused on construction site layout that is delimited as the design problem of arranging a set of predetermined facilities on a set of predetermined sites, while fulfilling a set of layout constraints and optimizing layout objectives. Yeh (1995)stated that for 10 facilities, the number of possible alternatives is over 3,628,000. Due to the complexity of facility layout problems, many algorithms have been developed to generate solutions for the problems. Also, the layout problem is a Non-Linear Program combinatorial optimization problem, that is, optimal solutions can be computed only for small or greatly restricted problems (Kusiak and Heragu 1987). The algorithms can be classified as layout improvement, entire layout and partial layout categories (Sirinaovakul and Thajchayapong 1996). Hence, layout planners often resort to using heuristics to reduce their search for acceptable solutions. These heuristics to comprise strategic knowledge prescribing the order in which to select objects and to meet constraints, and have been modeled with various degrees of truthfulness, detail, and success in operations research and artificial intelligence applications for space management [Tommelein, Levitt et al. (1991), Thabet (1992), Tommelein and Zouein (1993), Yeh (1995), Zouein (1995), Lin and Haas (1996), Zouein and Tommelein (1999)].

The result from literature over the last decade can be classified into two broad area of study; (1) space-scheduling and (2) site layout planning. Figure 2 explains the output of these approaches.

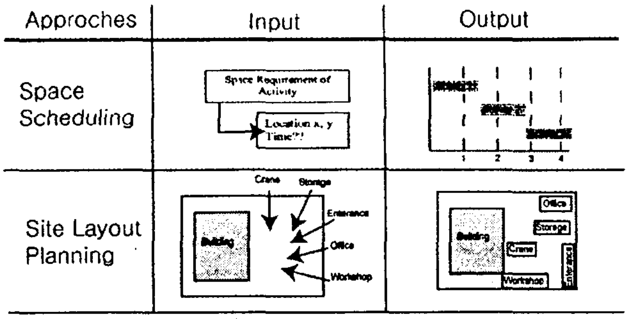


Figure 2: Two Different Approaches in the Construction Space Management (Akinci et al. 2000)

Researchers have tried many different algorithms such as static, dynamic, mathematic, or heuristics algorithms to allocate of construction facilities at site area automatically. Hence site layout approach is very similar to facility layout planning, which is shown in Figure 3.

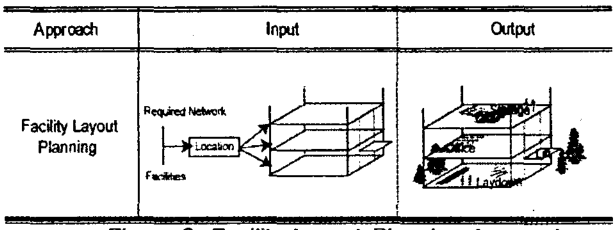


Figure 3: Facility Layout Planning Approach

In summary, the construction space management literature describes useful background information that explains comprehensive methods to automate the generation of building level facility layout planning. This paper complements the research done within the space management area by defining the necessary to generate building level facility layout from generic required network ordering of space needs.

## 4. Facility Layout Problem

The facility layout problem is generally defined as finding a feasible facility assignment that minimizes the interaction cost between the construction resources. An interaction cost between facilities is naturally expressed as the flow times of distance between locations following required activities and frequencies of trips made by workers between facilities. In general, facilities have unequal area requirements, and some of them may be constrained a priority to certain locations within the facility. Because the site level facility layout problem is modeled as a quadratic assignment problem in which costs associated with the flow between facilities are linear with respect to distance traveled and quantity of flow, many heuristics have been developed for it (Li and Love 2000).

The multiple-floor facility layout problem, on the other hand, encompasses all aspects of the site level facility layout problem, and in addition, it includes vertical flows and area constraints for individual floors. Vertical flows must utilize a lift, which is defined here as a generic vertical facility handling device. Moreover, because it is assumed that construction activities cannot be split across floors, some layouts may not be feasible in a multi-story building problem. This paper has described an approach for only the two dimensional problem. This problem is further categorized into layout problems with facilities of equal area Quadratic assignment problem and unequal area Non-quadratic assignment problem. Both categories include site-level and the multiple-floor layout problems. The facility layout algorithm must generate feasible layouts that satisfy the constraints imposed and minimize (maximize) the transportation cost and time. It is important to represent that any solution procedure should generate a layout that requires minimal manual adjustment and should be sensitive to varying shapes and sizes of periodic facilities and temporary facilities.

## 5. Multiple-Floor Facility Layout Explore

In most cases, the approach is to take the shortest from one major activity to another. The objective of multiple-floor facility layout is to minimize the total cost of facility handling. The formulation of objectives can be expressed as (1):

$$Min\sum_{i=1}^{n}\sum_{j=1}^{m} W_{a_i f_j} D_{a_i f_j} \quad \cdots\cdots (1)$$

*n : number of activities   m : number of facilities*

$W_{a_i f_j}$ is the weight ordering between facilities and activities. Coefficient $D_{a_i f_j}$ is the distance between an activity $a_i$ and a facility $f_j$. If ai and $f_j$ belong to the same floor, $D_{a_i f_j}$ is simply the horizontal distance between them. Otherwise, the sum of three distances is employed to $D_{a_i f_j}$ : horizontal distance between $f_j$ and the nearest lift, vertical distance between two floors, and the horizontal distance that lift is to $a_i$.

### 5.1 Assumptions

To improve the multiple-floor facility layout model, assumptions are described below;

1) A floor is divided into grids, so each facility occupies at least one grid and there is no grid sharing.
2) The size of a facility must be the smallest it can be but there is no limit to the number of facilities of the same type. For example, a brick, which can be size 1, must be size 1 but there can be several brick facilities each of them is size one.
3) The populations of the facilities whose sizes are bigger than one do not dominate the total population.
4) The distance between two facilities whose sizes are bigger than one grid unit, is the average distance between the grid units they occupy.
5) The shape of a facility must be a square or rectangle.

Cost Function The cost function for the multiple floor layout problems considers travel along the vertical direction as well as that in the horizontal direction. To transport facility between facilities located on different floors, a lift must be chosen from among the available vertical facility handling devices. The cost function shown below uses the following notation:

$C_{a_i f_j}$ The cost function

$D_{a_i f_j}$ The distance between an activity ai and a facility $f_j$

$W_{a_i f_j}$ The weight between an activity ai and a facility $f_j$

$P_i$ The three dimensional rectangular coordinate of $f_j$

$P_l$ The three dimensional rectangular coordinate of the closest lift

$H,V$ Horizontal and vertical cost of transporting a unit load through a unit distance

The total cost function $C_{a_i f_j} = D_{a_i f_j} \cdot W_{a_i f_j}$, where ai is an activity and $f_j$ is a facility.

$$C_{ij}\begin{cases}(z_i = z_j) & \|P_i - P_j\| \bullet W_{a_i f_j} \\ (z_i \neq z_j) & (\|(P_i - P_l)\bullet H\| + \|(P_j - P_l)\bullet H\| + \|(P_i - P_j)\bullet V\|)\bullet W_{a_i f_j} \end{cases} \cdots\cdots$$

$$H = \begin{bmatrix}1 & 0\\ 0 & 1\\ 0 & 0\end{bmatrix}, \quad V = \begin{bmatrix}0\\ 0\\ k\end{bmatrix} \quad k = \text{cost factor for lifting material from floor i to floor j}$$

## 6. Experiment Problem

For the experiment of the number of generations in efficiency of the search and the performance of GA, a range of zero to five hundred generations was chosen. An eight-story building with seven activities, twenty-two temporary facilities, and two periodic facilities were created for the experimentation of the program initialization (Table 1). In addition, a dummy and lift were set up for the experimentation.

Table 1: Experiment Input Information

| Activity | (Facility, Size, Weights) | Floor |
|---|---|---|
| a1 | (f1,3,3.5), (f2,4,1.3), (f3,2,1.6) | 6,7,8 |
| a2 | (f4,2,3.0), (f5,2,1.6) | 7,8 |
| a3 | (f6,5,4.0), (f7,3,2.3), (f8,4,1.2), (f9,2,3.1) | 6,7 |
| a4 | (f10,1,1.9), (f11,2,2.6) | 2,4,5 |
| a5 | (f12,2,1.8), (f13,2,1.3), (f14,3,2.2) | 2,3,4 |
| a6 | (f15,1,2.1), (f16,2,0.9), (f17,3,1.6), (f18,1,1.2), (f19,2,2.8) | 3 |
| a7 | (f20,3,0.6), (f21,4,2.8), (f22,1,3.0) | 2 |

### 6.1 Result of Experimentation

After running the program ten times, it was discovered that there is no significance change in results after the 400th generation. Figure 4 shows a plot of minimum values of the cost function against the number of generations.

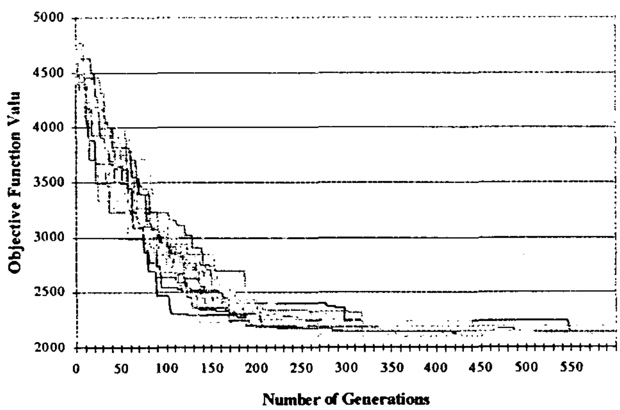


Figure 4: A Comparison of The Number of Generations

The resulting floor plan is depicted in Figure 5. Total 300 grids by 20 X-axis and 15 Y-axis were represented and each grid has a 4'*4'size. The running time was 1 minute and 23 seconds. The optimal objective function value is 2104.7187.

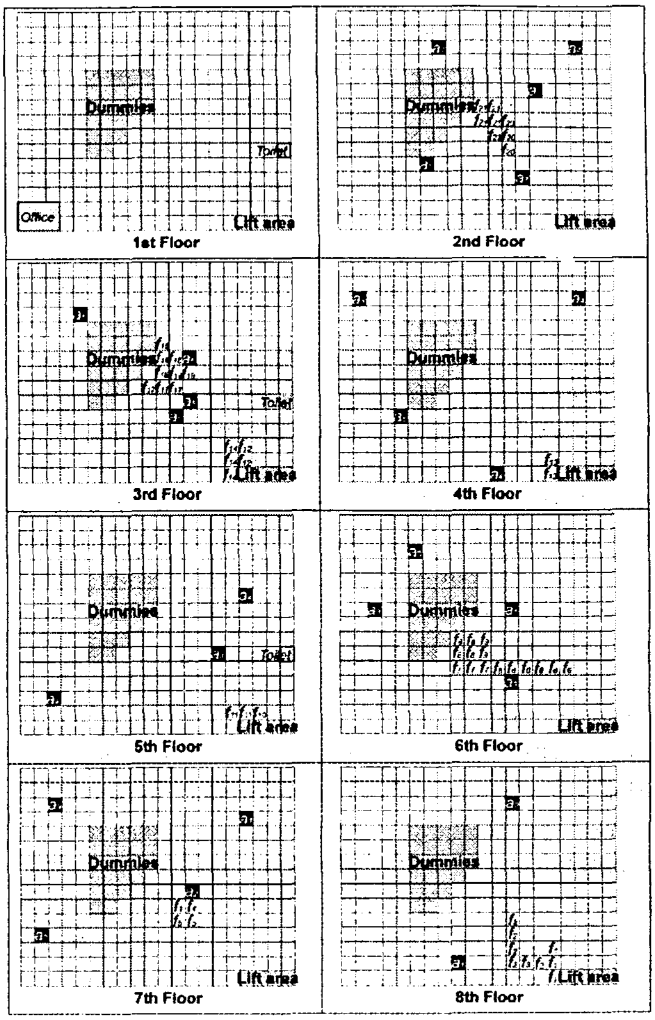


Figure 5: Optimal Floor Plan Output

## 7. Conclusion

Genetic Algorithm (GA) modeling assumptions are made in order to properly allocate space for facilities that will result in lower computational costs and increases in productivity. The following conclusions were made based on the work; (1) the construction facility layout problem on high-rise buildings can be represented successfully using the GA modeling described in this paper, (2) GA modeling can be applied to generate workable layouts if an objective function is based on quantitative parameters. It is recommended for further development of the model can be extended to evaluate the effectiveness of the overall construction facilities layout planning.

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## Abstract


건설공사 현장에서 공간활용을 위해 가장 보편적으로 쓰이는 방법이 site plans 이다. 이 방법은 건설 물자재를 적재하고 운반할시 공간이 부족한 도심지 부근에서 어떻게 건설 물자재를 옮기고 적재하는가? 크레인의 위치는 어디에 선정할것인가? 하는 문제를 해결하기 위한 것이다. 본고는 이러한 문제를 수평적으로 해결함과 동시에 수직적으로도 해결할 수 있는 방안을 도출했다. 이러한 해결 방안은 건설현장을 지도 또는 감독하는 메니져에게 가장 효과적으로 건설 물자재를 적재시켜 줄 수 있어 방법론을 제시함으로써 공기의 단축을 가져올 수 있는 효과를 누릴 수 있다. 방법론으로는 Genetic Algorithm을 이용하여 multiple-floor layout 문제점 해결하였다.



**키워드 : 건설물자재(Construction Facilities), 구획문제(Layout problems), 지네틱 알고리즘(Genetic Algorithm)**